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Richard E. Reedy

OFFICE SECURITY ADVISOR

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TRANSPORT HELICOPTER OPERATING COST ANALYSIS METHODS

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FOR THE
UNITED STATES ARMY
THROUGH THE
OFFICE OF NAVAL RESEARCH - AIR BRANCH

Report No. 360.1

30 November 1955

ENGINEERING DIVISION

HILLER HELICOPTERS

MAR 14 1956

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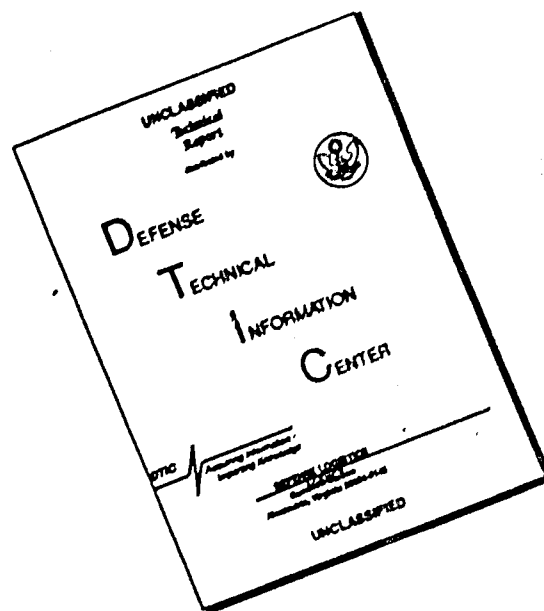
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TRANSPORT HELICOPTER
OPERATING COST ANALYSIS
METHODS

Report No. 360.1
30 November, 1955

Contract No. Nonr-1340(00)

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ENGINEERING DIVISION - HILLER HELICOPTERS

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FORWARD

The extensive study of helicopter operating costs covered in this report was undertaken within the framework of a broad evaluation of "Military Helicopter Transport Systems", under Contract Nonr-1340(00) for the U. S. Army through the Office of Naval Research.

The measure of operational effectiveness which was used in this evaluation was "ton-miles per military dollar" and, therefore, encompassed the following problem components:

1. Combat Element Airlift Support Requirements
2. Helicopter Design Selections
3. Helicopter Operational Factors
4. Transport System Costing

The fourth of these problem components necessitated the investigations which are described in this report.

In an additional report, Hiller Helicopters Report No. 473.6, entitled "Transport Helicopter Design Analysis Methods", the area of problem component 2 above is covered and a complete chart technique for transport helicopter design optimization is derived and presented.

Problem components 1 and 3 are covered within the final summary report on this contract, "Military Helicopter Transport Systems - 1956 to 1961", Hiller Helicopters Report No. 350.1.

Hiller Helicopters Report No. 473.6 also presents the complete set of tables required to determine total flight-hour or ton-mile costs using the equations and charts presented herein.

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NOTE: The maintenance cost charts of Section 3, Part D, on Pages 24 through 61 of this report, were originally included as a portion of Report No. 473.0, Part 5, Section C, and as such were declassified from CONFIDENTIAL to NO SECURITY by ONR letter ONR:461:WGR:ew, Serial SER11404, dated 19 May, 1955.

Pages 24 through 61 of this report may therefore be copied or reproduced for unclassified use.

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TRANSPORT HELICOPTER
OPERATING COST ANALYSIS
METHODS

I. INTRODUCTION

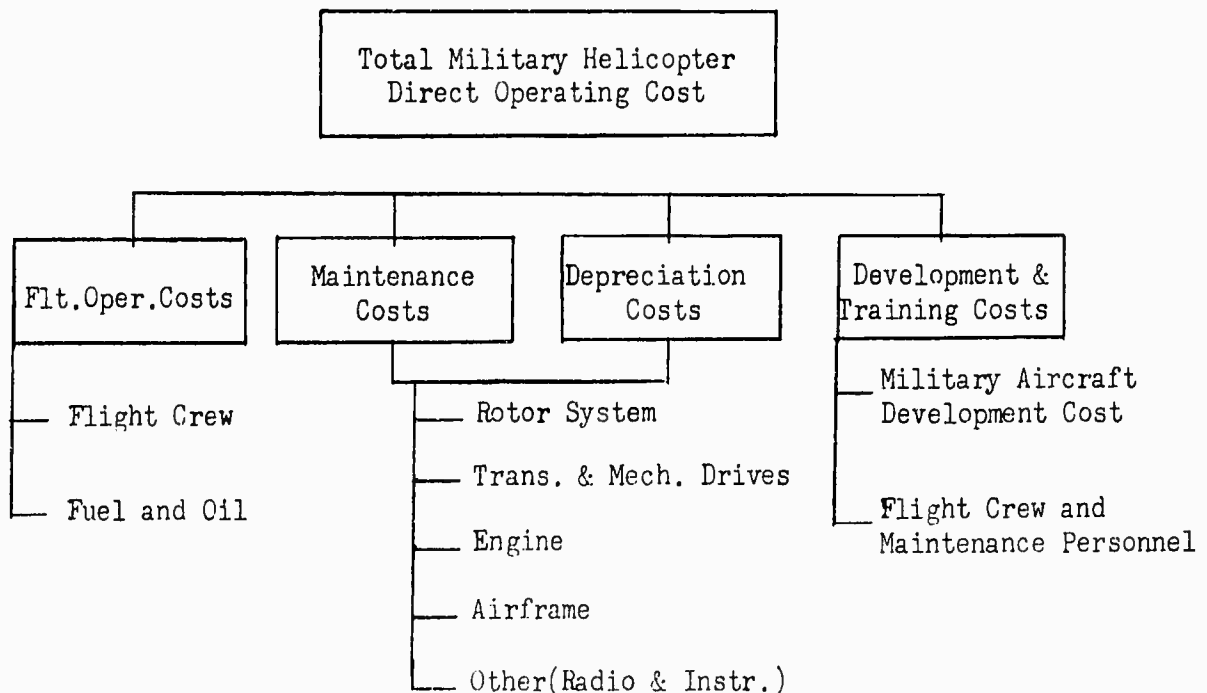
The methods outlined in this report have been developed for the purpose of estimating direct operating costs of present and future transport type military helicopters, as well as for evaluating preliminary design data of proposed models.

At the present stage of development and use of the Military Transport Helicopter, the Army maintenance cost data which is available appears somewhat scattered as to its source, indefinite in its breakdown and, in general, of not sufficient detail or consistency to be used in predicting trends, or in estimating unit flight-hour costs.

In addition, Army costing practices regarding first and second echelon maintenance are such that a large amount of indirect cost is included in the operating cost data. These costs are, of course, valid, but they are not expenses which can be directly associated with the operation of the aircraft, nor do they change with any variation in the aircraft's design or performance parameters.

For these reasons the maintenance cost data used in developing the cost trends in this study reflect a large volume of commercial operators' statistical information. This data has been collected and studied, and is of sufficient detail so as to allow a maintenance cost breakdown into the functional component groups.

The costing methods have been divided into the general areas as shown schematically below:



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3-ton payload: Pilot (W/O)
Co-pilot (W/O)
Crew Chief (E-7) or
Flight Engineer (W/O)

5-ton payload: Pilot (W/O)
Co-pilot (W/O)
Flight Engineer (W/O)

Recognizing that these crew arrangements reflect present tentative thinking, and that some other crew arrangement and grade may be used when helicopters of the sizes indicated become operational, flight crew costs based on this schedule appear to be the best for present planning purposes.

The present average annual pay for the two grades are:

W/O - - - \$5225.00/year
E-7 - - - \$4620.00/year

In determining hourly costs, it seems reasonable to assume a crew utilization of 1000 hours/year. This amounts to less than 4 flight hours per day, and is believed to be realistic for an actual military operation. It is further justified by the experience of the Military Air Transport Service, which uses the same value.

Since no definite feeling has been found with regard to the choice of a flight engineer or a crew chief in the 3-ton payload class, a flight engineer can be conservatively assumed for this payload class.

Based on the foregoing assumptions, then, the total flight hour crew costs are summarized as follows:

1-ton payload: \$15.07/flt. hour
3 and 5-ton payload: \$15.68/flt. hour

For transport type helicopters having payload capacities in the above vicinity, an average figure for total flight-hour crew cost of $C_c = \$15.37/\text{flt. hour}$ may be assumed.

B) Fuel and Oil

These costs may be shown as follows:

$$C_f = W_f \left(\frac{V_B}{R} \right) K_f \qquad C_o = W_o \left(\frac{V_B}{R} \right) K_o$$

where C_f = Fuel cost (Dollar/flt. hour)
 W_f = Fuel weight (lbs) including reserve

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Each of these areas is discussed within this report and the equations for calculating the detail cost items are presented together with the graphical chart results of a thorough statistical study of helicopter maintenance costs.

The flight operations costs are based on Military practices and data, and for this reason do not include the insurance and training categories normally found in a commercial operator's cost analysis.

The depreciation costs are also based on present Military practices in determining depreciation period and residual value. The first costs are based on a statistical study of present production helicopter costs.

It is believed that this approach will best represent the actual direct operating cost of any transport helicopter in military operations. Since much of the data has been extrapolated in order to allow cost predictions of helicopters up to the empty weight vicinity of 70,000 lbs., the actual dollars and cents values found cannot be accepted as fully quantitative. However, the values will provide a means of sensible comparison of one transport configuration to another. In addition, the unit flight-hour maintenance trends are significant.

The cost analysis technique is divided into the four major areas of:

- 1) Flight operations
- 2) Maintenance
- 3) Depreciation
- 4) Development and training

Categories 2 and 3 are further broken down into functional component groups and the background data for each will be outlined and discussed. The data is broad enough to include various tip-power type configurations as well as the shaft drive reciprocating and gas turbine power plants.

II. FLIGHT OPERATIONS COSTS

The flight operations cost is separated into the categories of:

- A) Flight crew
- B) Fuel and oil cost

A) Flight Crew

Present military planning for large transport helicopter operations indicates the following crew requirements for the three general payload classes of one ton, three tons and five tons:

- 1-ton payload: Pilot (W/O)
Co-pilot (W/O)
Crew Chief (E-7)

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3-ton payload: Pilot (W/O)
Co-pilot (W/O)
Crew Chief (E-7) or
Flight Engineer (W/O)

5-ton payload: Pilot (W/O)
Co-pilot (W/O)
Flight Engineer (W/O)

Recognizing that these crew arrangements reflect present tentative thinking, and that some other crew arrangement and grade may be used when helicopters of the sizes indicated become operational, flight crew costs based on this schedule appear to be the best for present planning purposes.

The present average annual pay for the two grades are:

W/O - - - \$5225.00/year
E-7 - - - \$4620.00/year

In determining hourly costs, it seems reasonable to assume a crew utilization of 1000 hours/year. This amounts to less than 4 flight hours per day, and is believed to be realistic for an actual military operation. It is further justified by the experience of the Military Air Transport Service, which uses the same value.

Since no definite feeling has been found with regard to the choice of a flight engineer or a crew chief in the 3-ton payload class, a flight engineer can be conservatively assumed for this payload class.

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For transport type helicopters having payload capacities in the above vicinity, an average figure for total flight-hour crew cost of $C_c = \$15.37/\text{flt. hour}$ may be assumed.

B) Fuel and Oil

These costs may be shown as follows:

$$C_f = W_f \left(\frac{V_B}{R} \right) K_f \qquad C_o = W_o \left(\frac{V_B}{R} \right) K_o$$

where C_f = Fuel cost (Dollar/flt. hour)
 W_f = Fuel weight (lbs) including reserve

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V_B = Block speed - Ton Naut.Miles/Hour
 R = Range or trip length - Naut. Miles
 K_f = Unit fuel cost (Dollars/lb.)
 C_o = Oil cost (Dollars/Flt.Hour)
 K_o = Unit oil cost (Dollar/lb.)

The following table presents the fuel and oil costs and densities, based on large lot sales, to the U. S. by the fuel manufacturers:

	Reciprocating Engine Fuel 100/130 Octane	Turbine Engine Fuel JP-4	Oil
Dollar Cost/Gal.	.216	.113	.50
Weight(lbs)/Gal.	6.0	6.5	7.5
K_f or K_o	.0360	.0174	.0667

A comparison of the average cruise specific oil and fuel consumptions of a large number of operational reciprocating engines gives

$$\Delta_{oR} = \left(\frac{W_o}{W_f} \right) = \frac{SfC_{oil}}{SfC_{fuel}} = \frac{.025}{.600} = \frac{1}{24} \quad \text{Reciprocating Engines}$$

A similar comparison of turbine engines yields

$$\Delta_{oT} = \left(\frac{W_o}{W_f} \right) = \frac{SfC_{oil}}{SfC_{fuel}} = \frac{.0015}{.75} = \frac{1}{500} \quad \text{Turbine Engines}$$

Combining the equations for fuel and oil cost gives

$$C_f + C_o = W_f \left(\frac{V_B}{R} \right) K_f + \Delta_o W_f \left(\frac{V_B}{R} \right) K_o$$

$$C_{f,o} = W_f \left(\frac{V_B}{R} \right) [K_f + \Delta_o K_o]$$

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Letting $K_{fo} = K_f \Delta_o K_o$
 gives $C_{f+o} = K_{fo} W_f \left(\frac{V_B}{R} \right)$

The values for K_{fo} for various power plant types are shown in the following table. JP-4 fuel has been assumed for the ramjet engine.

Power Plant Type	K_{fo}
Reciprocating	.04
Turbine	.02
Ramjet	.517

For preliminary design and analysis use, the fuel and oil cost equation can be rewritten in the following form:

$$C_{f+o} = K_{fo} R_f W \left(\frac{V_B}{R} \right)$$

where $R_f = \text{fuel weight ratio} = \left(\frac{\text{Weight of Fuel}}{\text{Gross Weight}} \right)$

$W = \text{Design Gross Weight}$

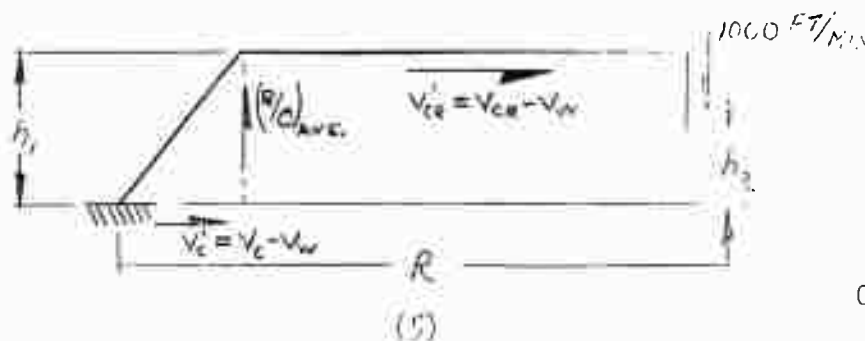
For conservative estimates the fuel weight used in the above equations may be taken as the fuel weight required for the particular trip length and wind condition with the appropriate reserve included.

Determination of Block Speed

The block speed may be defined as follows:

$$V_B = \frac{R}{t_{CR} + t_{CL} + t_D + t_m} = \frac{R}{\text{Total time}}$$

The sketch shown below will indicate an assumed flight plan which allows no distance credit in descent as outlined in MIL Spec MIL-C-5011a.



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h_1 = Cruise altitude - take-off ground altitude (Ft)

$(h_1 - h_2)$ = Cruise altitude - Landing ground altitude (Ft)

V_{CR} = Cruise speed (Knots)

V_W = Average assumed wind velocity (Knots)

V_C = Climb speed (horizontal velocity during climb) (Knots)

(R/C) = Rate of climb (Ft/Min)

R = Range or trip length (Naut. miles)

t_{CR} = Time to cruise (Hours)

t_{CL} = Time to climb (Hours)

t_D = Time to descend (Hours)

t_m = Time to maneuver (Hours)

Superscript (') = indicates speed corrected for wind velocity (V_W)

Assuming a constant descent rate of 1000 ft/min (partial power), the total time is

$$\text{Time} = \underbrace{\frac{h_1}{60(R/C)}}_{\text{Climb}} + \underbrace{\frac{(h_1 - h_2)}{60,000}}_{\text{Descent}} + \underbrace{\frac{R - V_C' \frac{h_1}{60(R/C)}}{V_{CR}'}}_{\text{Cruise}} + \underbrace{t_m}_{\text{Maneuver}}$$

Combining terms gives

$$\text{Time} = \frac{h_1}{60(R/C)} \left(1 - \frac{V_C'}{V_{CR}'} \right) + \frac{h_1 - h_2}{60,000} + t_m + \frac{R}{V_{CR}'}$$

Then let

$$\Delta t = \frac{h_1}{60(R/C)} \left(1 - \frac{V_C'}{V_{CR}'} \right) + \frac{h_1 - h_2}{60,000}$$

and the block speed becomes

$$V_B = \frac{R}{\Delta t + \frac{R}{V_{CR}'} + t_m}$$

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The maneuver time as outlined in MIL-C-5011A may be assumed to be

$$t_m = .0833 \text{ hrs. (Reciprocating power plants)}$$

and $t_m = .0333 \text{ hrs. (Turbine power plants)}$

This time allowance covers the allowance for engine warm-up, take-off and accelerate to climb. The block speed, then, considers the time from "start engines" to engine "shut-down" at completion of mission. No taxi time is assumed.

III. MAINTENANCE COSTS

A. General Outline of Maintenance Cost Study

The investigation of maintenance costs presented the most difficult obstacles of all the direct operating cost studies. Maintenance costs, unlike the other direct cost items, do not allow a straight-forward or pure logical evaluation. The only way in which a realistic estimation of the operating cost of a particular piece of aircraft hardware can be made is from data based on previous operation of similar types of units. At the onset of this particular study, no such empirical data was available.

It became necessary, therefore, to collect as much operating cost data as possible, from as wide a distribution as was feasible, in the allowable time. This cost data was collected and analyzed in order to develop the necessary trends.

Most of the raw data was purely statistical and not always as complete as was desired. For this reason, certain analytical techniques were employed to develop the complete maintenance cost picture. This was done in order to make the study as broad as possible and to allow the detailed maintenance cost analysis of not only presently operating helicopters, but also of those which might become operational in the reasonably near future.

The data breakdown desired in the analysis was of a detailed nature so that it could be used on any transport helicopter configuration and would allow the detailed study of certain component groups.

Since the greatest bulk of the statistical operating cost information on power plants was on the reciprocating type, a certain void was present when shaft drive turbine, ramjet, pressure jet, and tip-mounted turbine systems were considered. This, of course, was because of the complete lack of any helicopters with these types of power plants in any large scale commercial or military operations. The void was filled by collecting as much data as possible on these types of power plants and by adjusting it to fit the helicopter propulsion picture on the basis of present reciprocating engine helicopter data trends. Obviously, this engine data cannot be considered as valuable, quantitatively speaking, as that based on the statistical information for reciprocating

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power plants. It does, however, indicate general order of cost magnitude and shows basic operating cost differences between one type of installation and another.

Actual tandem helicopter maintenance costs are not reflected in the statistical cost information. To date, there have been no tandem configurations used in commercial helicopter operations, and since the maintenance cost trends were based on commercial operators' statistical data they do not indicate whether a difference in unit flight-hour cost per pound of component weight would exist between single rotor and tandem rotor configurations.

Military cost data¹ was examined in an effort to settle this problem but was found to be inconclusive since the data for only one tandem rotor type was represented.

The final cost trends are presented in great detail so that labor cost can be separated from material cost for all component system groups. The basic component groups into which the data are separated are as follows:

- 1) Rotor Systems
- 2) Transmission and Drives Systems
- 3) Airframe
- 4) Engines
- 5) Other (Radio and Instruments)

The engine maintenance costs are shown for the following types of power plants:

- 1) Reciprocating
- 2) Gas Turbine
- 3) Ramjet

In addition, a cost analysis approach is suggested for the pressure jet and tip mounted turbine types, utilizing the basic reciprocating and gas turbine trends mentioned above.

B. Data Reduction and Method of Analysis

1. Data Collection

The collection of maintenance cost data was undertaken for the purpose of gathering information which would allow the analysis of some of the details of helicopter maintenance costs in order to develop the trends which might be expected with the advent of larger and more complex equipment.

In this respect, an intensive survey was carried out, during which time responsible personnel, representing a large number of all operators now using the helicopter commercially, were contacted in an effort to gain statistical helicopter maintenance data.

¹ Analysis of Army Aircraft Operating and Maintenance Costs. Project 9-72-02-001, July, 1955 - Army Aviation Div. TRADCOM, Fort Eustis, Virginia

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During this survey, representatives of Helicopter Air Services, New York Air Ways, Mohawk Air Lines, National Air Lines, United Air Lines, Eastern Air Lines, American Airlines, and the Air Transport Association were contacted personally, in addition to Army and Navy personnel having cognizance of military helicopter maintenance problems. The result of these conferences was the gathering of a large volume of detailed helicopter and airplane maintenance data which has proved to be very useful in the subject study.

At the present state of development and use of the military transport helicopter, available Army maintenance cost data appeared somewhat scattered as to source, indefinite in breakdown, and, in general, not of sufficient detail or consistency to be used in predicting trends or in estimating unit flight hour costs. Military cost data allowed an estimation of total cost factors, but it was necessary to utilize commercial operating cost information in establishing the trends of cost versus the pertinent variables. By using the trends based on commercial data, as shown in Section III-D of this report, together with the total cost ratios found to exist between commercial total cost and military total cost, a reasonable estimate of the total maintenance cost can be obtained for any given military design configuration.

2. Military Cost Level Correction - K_{CM}

As mentioned previously, the available data on military maintenance costs gave insight only to the total cost, and when this was compared with the commercial cost total, a factor of 2.5 was indicated, representing the ratio of military cost to commercial cost.

The factor does not consider the indirect cost of the support of the many maintenance personnel whose direct labor make up the labor cost portion of the total maintenance cost. It does not, therefore, include the cost of feeding, clothing and housing helicopter maintenance personnel.

Intuitively, the factor of 2.5 might well be expected, since the over-all complexity of military supply support systems are, of necessity, considerably more complicated than those found in similar commercial operations.

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3. Data Analysis and Tabular Cost Forms

The maintenance cost information from each data source was broken down and tabulated on each of the two forms shown in Figure 1 on the following page.

This breakdown allowed the separation of labor and material cost as well as the isolation of the costs of each of the pertinent system groups. In addition, flight line and overhaul costs were separated. In Table A, overhaul and limited life parts retirement were considered separately. Table B relates the various group costs to the standard fixed wing CAB account numbers, which the commercial helicopter air carriers are now forced to use. Table B also relates the total group labor and material costs to the total weight of the group.

4. Component System Group Breakdown

The system groups considered were as follows:

- 1) Rotor Systems
- 2) Transmissions and Mechanical Drive Systems
- 3) Airframe (Structure, Landing Gear Controls, Accessory Systems, etc.)
- 4) Engines
- 5) Other (Radio and Instruments)

These system groupings were chosen on the premise that they each display certain maintenance areas which are different from one another not only in the magnitude of the maintenance cost but also in the trends which these costs reveal when plotted against the system group weight. Specifically, each of the system groups chosen represents a particular type of helicopter hardware with its own typical maintenance problem areas. The system group weights include the following items:

Rotor System Weight

The group weight for the system including rotor hubs, blades, and blade retention hardware. The group includes both main and auxiliary rotors.

Transmission and Drives Weights

This weight includes all of the components within the main and auxiliary drive systems and considers all shafting and transmissions.

Engine Weight

Installed weight of the power plant, including starting and cooling systems.

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MAINTENANCE COST DATA ANALYSIS FORMS

HELICOPTER MAINT. COST TABLE - TABLE 'B'

CAB ACCOUNT NOS. →				524X			522X			GROUP TOTALS			
LINE	ITEM	WIGHT	MATERIALS COST/HOUR	LABOR COST/HOUR	TOTAL	LINE	ITEM	WIGHT	TOTAL	TOTAL COST/HK	TOTAL WEIGHT		
5241	5241					5221	5221						
5242	5242					5222	5222						
5243	5243					5223	5223						
5244	5244					5224	5224						
5245	5245					5225	5225						
5246	5246					5226	5226						
5247	5247					5227	5227						
5248	5248					5228	5228						
5249	5249					5229	5229						
5250	5250					5230	5230						
5251	5251					5231	5231						
5252	5252					5232	5232						
5253	5253					5233	5233						
5254	5254					5234	5234						
5255	5255					5235	5235						
5256	5256					5236	5236						
5257	5257					5237	5237						
5258	5258					5238	5238						
5259	5259					5239	5239						
5260	5260					5240	5240						
5261	5261					5241	5241						
5262	5262					5242	5242						
5263	5263					5243	5243						
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5265	5265					5245	5245						
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5267	5267					5247	5247						
5268	5268					5248	5248						
5269	5269					5249	5249						
5270	5270					5250	5250						
5271	5271					5251	5251						
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5274	5274					5254	5254						
5275	5275					5255	5255						
5276	5276					5256	5256						
5277	5277					5257	5257						
5278	5278					5258	5258						
5279	5279					5259	5259						
5280	5280					5260	5260						
5281	5281					5261	5261						
5282	5282					5262	5262						
5283	5283					5263	5263						
5284	5284					5264	5264						
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5299	5299					5279	5279						
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5386	5386					5366	5366						

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Other Weight

Weight of radio equipment and instruments.

Airframe Weight

This is the basic weight empty, less engine, rotor system, transmission and mechanical drives, and "other" group weights, as shown above.

The total of all the group weights comprises the operating empty weight of the aircraft.

5. Summary of Reduced Cost Data

After processing all of the helicopter maintenance cost information from each data source, through the Tables shown in Figure 1, the average values for a particular system group and a particular configuration were determined. The results of this procedure are depicted in Figure 2 on the opposite page. Figure 2 presents a tabulation of the results of the statistical maintenance cost data for the Sikorsky S-55 and the Bell Model 47 Helicopters. However, some of the Bell Model 47 data was augmented by Hiller operators' data on the UH-12A and the Hiller Model 12-B, where applicable. Obviously, in a statistical sampling of such information, more configurations would be desired, but the Sikorsky S-55, Bell 47, and Hiller 12-B are the only three helicopters in extensive commercial operation in the United States at the present time. The table lists all of the pertinent cost data for each system group with the labor, material, and total costs all shown on a flight hour basis. In addition, the group cost to total cost percentage is shown, as well as the percentage overhaul and limited life parts retirement cost. Average component overhaul period and component life are also presented.

It may be seen, as might be expected, that the rotor systems and transmissions and mechanical drives groups display the highest cost percentages. This seems, primarily, to be because of the low overhaul periods and the relatively short limited life of the components which make up these two system groups in presently operating helicopters. These systems have overhaul periods averaging 400 to 500 hours and an average limited life parts retirement of 2000 hours.

6. Chart Presentation of Data

The data of Figure 2 are presented in chart form under Item C-4 of this section. Charts of labor hours, labor cost, material cost, and total maintenance cost, on a flight hour basis, are plotted versus the system group weight and the basic weight empty less engine system group weight for each of the component system groups.

It may be noted that material costs represent the highest percentage of the total group costs for the rotor systems, transmissions and mechanical drives

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MAINTENANCE CCS' DATA SUMMARY

Group	Type	Weight (lbs.)	Labor Hrs. per Flight Hour	Average Labor Rate \$/Hour	Labor Cost per Flight Hour	Material Cost per Flight Hour	Total Cost per Flight Hour	Percent Group Total	Total Overhaul or Lm. Life Parts Cost	Percent Overhaul Total	Average Component Overhaul Period	Average Component Life
Airframe	S-55	2331	1.18	2.22	2.62	.19	2.81	6.35	--	--	--	--
	Bell 47	877	.875	1.93	1.69	.80	1.77	10.42	--	--	--	--
Engine	S-55	1026	1.1	2.04	3.75	5.14	9.29	21.00	5.36	4.2	600 hrs.	--
	Bell 47	393	1.395	1.93	2.48	2.13	4.71	27.73	2.13	15.2	600 hrs.	--
Rotor Systems	S-55	861	.75	2.17	1.85	16.65	18.70	42.20	7.89	42.2	400 hrs. 2000 hrs.	
	Bell 47	255	.70	1.93	1.41	3.30	4.71	27.73	10.05	53.7	500 hrs. 2000 hrs.	
Trans. & Red. Drives	S-55	503	1.20	2.10	2.1	9.56	12.46	26.10	2.37	50.4	500 hrs. 2000 hrs.	
	Bell 47	153	.673	1.93	1.30	4.00	5.30	31.20	1.51	33.6		
Other	S-55	254	.344	2.18	.75	.30	1.05	2.35	2.18	41.1		
	Bell 47	62	.181	1.93	.35	.15	.50	2.92	1.15	21.7		
Totals	S-55	4975	5.314	2.23	11.85	34.46	44.31	100 %	24.55	55.4	400-600	2000
	Bell 47	1550	3.784	1.92	7.33	9.66	16.99	100 %	6.60	30.3	400-600	2000
									2.74	16.1		

NOTE: BELL MODEL 47 DATA
AUGMENTED BY HILLER
MODEL 12-B DATA
WHERE APPLICABLE

FIGURE 2

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systems, and engines groups. This is due primarily to high limited life parts replacement cost and, to a large extent, to overhaul material cost.

Labor costs appear as only a small percentage of the total cost. It is this fact which seems to make the total maintenance cost plot the most valuable. In addition, of course, this selection would reduce the number of charts required in making any specific analysis. However, to allow a more detailed cost study, the other plots have been included.

Upon inspection of the trends shown, it may be seen that a major topic demanding one's interest and concern is the fact that the maintenance cost data in general has been extrapolated over the greater percentage of the weight range of the chart. In order to predict the trends on up to and including possible transport helicopter configurations with empty weights in the neighborhood of 70,000 pounds, this extrapolation has been necessary. The helicopters now in service from which this data has been collected are definitely in what might be called a light-weight category, in comparison with fixed wing transport equipment. This necessitates the extrapolation which many years of fixed wing data have indicated to be linear. The points through which the trends have been drawn and extrapolated represent average cost figures gathered from the airlines and operators as previously mentioned.

The trends are presented for the conditions which exist today with the data clearly indicating the power loading and average limited life parts retirement for the particular component system group involved. In addition to the trends representing currently operating helicopters, the data is extended to allow an estimate of future operating costs corresponding to different design power loadings and longer component limited life.

Since the maintenance cost data is presented in terms of both the component system group weight and the basic empty weight less engine system group weight, some question arises as to which weight criterion to use. When operating cost comparisons are being evaluated between designs which differ from one another in configuration type, where the weight ratios of the basic group weight to empty weight differ from one design to the next, then the component system group weight is the logical choice. However, if helicopters of the same general power plant type and rotor configuration are being studied, the basic weight empty less engine system group weight can be used. This technique can only be used, however, if reciprocating power plants are being used in the designs, since the data plotted versus the basic weight empty less engine system weight was for reciprocating engine installations only. It may be seen, then, that the detail system group breakdown of costs versus the particular component system group weight allows the maintenance cost study of all configurations of rotor systems together with any power plant type, and affords the determination of the critical maintenance areas.

C. Analytical Extensions of Data

As was mentioned previously, some analytical techniques were employed in extending

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the data to transport helicopter types not now in service, in consideration of possible changes in design philosophy for future operational helicopters. One of these extensions was made for consideration of the effect of power loading on maintenance cost.

1. Engine Overhaul Period Relationship to Design Power Loading

Upon studying the maintenance cost trends resulting from the statistical data reflecting the cost trends of currently operating helicopters, some explanation was sought for the high magnitude of the costs when compared with fixed-wing maintenance cost data.

After a careful study of the helicopter cost information, together with airline cost data and a review of some of the pertinent design parameters of both types of aircraft, it was found that design power loading was closely related to engine overhaul period.

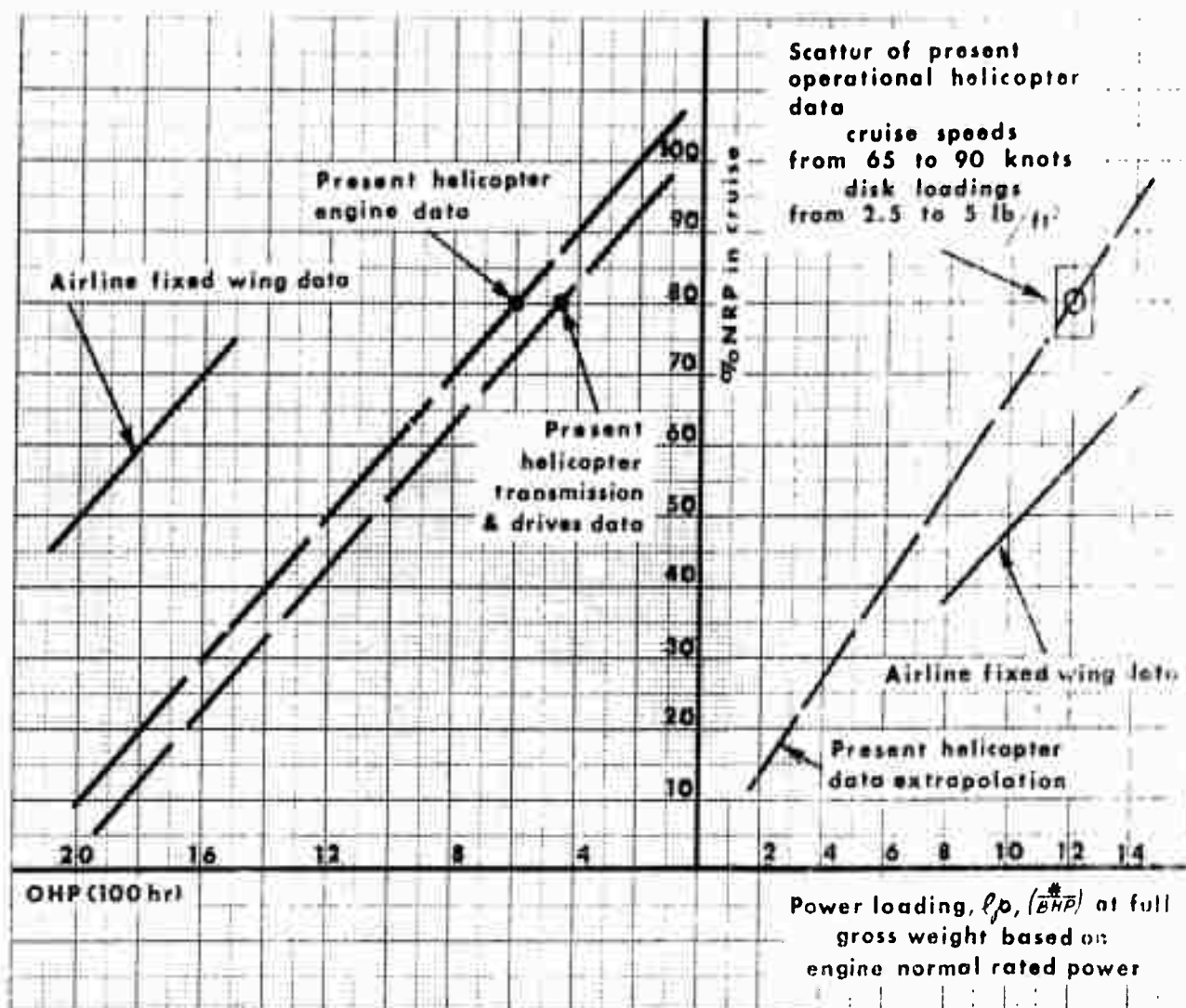
Since the percentage of normal rated power used in cruising is directly related to the design power loading, it seemed that overhaul period could be shown as a direct function of design cruise power loading. Figure 3 on the following page is a nomograph presentation of overhaul period as a function of cruise percent power setting and design normal rated power loading for airplane engines, helicopter engines, and transmissions and drives systems.

The point shown on the helicopter engine curve on the left half of Figure 3 indicates an average overhaul period of 600 hours for engines and 450 hours for transmissions and drives, for all of the helicopters now operational. As noted on the right half of Figure 3, these helicopters display an average power loading of 12 lb/BHP and an average cruise power setting of 80 percent NRP (normal rated power). The actual scatter about this average point ranges from 75 percent to 85 percent NRP in cruise, and power loadings from about 11.5 to 12.5 lb/BHP. The cruise speeds of these helicopters range from 65 knots for the smaller machines (which have proportionately higher drag per pound gross weight) to about 90 knots for the largest. With these cruise speeds held constant, the addition of more installed power (decrease in power loading) will result in a linear decrease in percent NRP in cruise as indicated by the dashed line extrapolated through the established point.

2. Extension of Power Loading Effect to Transmissions and Drives Systems

Since the design of the transmission and drive systems is based on the maximum engine power available, it might certainly be expected that an increase in average overhaul periods would occur in the transmission and drive components were they operated at lower helicopter design cruise power loadings.

Since presently operating helicopters indicate average overhaul periods of 450 hours for the transmissions and drives components with an average helicopter design cruise power loading of 80 lbs/BHP, this point is also shown in Figure 3. A trend parallel to the engine overhaul period variation is then assumed, which



HELICOPTER ENGINE AND TRANSMISSIONS
& DRIVE SYSTEMS OVERHAUL PERIOD VARIATION
WITH DESIGN POWER LOADING

Fig. 3

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would seem reasonable. This extension of the power loading effect on transmission and drive system component overhaul period seems logical when considering the design loading conditions in this particular type of helicopter "hardware". Transmissions and drive systems components are designed primarily on the basis of torque, which, in turn, is a function of power. Furthermore, the items which constitute the important overhaul areas in the transmissions and drives groups are influenced primarily by torque loading so that a reduction in cruise torque loading can very well be expected directly to reduce the required overhaul period.

In considering an extension of the "power loading effect" to the overhaul period of rotor systems, it does not appear logical to apply an extension to all of the components of the rotor systems group. This is primarily due to the fact that the major loading on rotor system components does not stem mainly from power considerations, but is a function of rotor lift forces and blade centrifugal loads as well. A study of the components in helicopter rotor systems, of both the flapping and teetering type, revealed that only about ten percent of the system components are affected to any great extent by torque loads. Those which were loaded in a torque reacting fashion had, in addition, loads due to blade bending, rotor thrust or centrifugal force which predominated.

The low magnitude of the power loading effect on the airframe and "other" groups seemed so self-evident that its consideration was excluded.

3. Effect of Fatigue Life Improvement

As can be seen from Figure 2, shown previously, the average fatigue life of components in all groups is 2000 hours for presently operating equipment. In consideration of the rapid advancement of the design "state of the art", particularly as it has affected the knowledge of fatigue failures in helicopter components and has brought about new analysis techniques in preventing fatigue failures in the design stage, it might well be expected that future designs will exhibit larger fatigue life limits.

When considering helicopter transports which might be entering initial production in about 1960, the feeling has been expressed by many structural designers, prominent in the helicopter airframe manufacturing industry, that the average fatigue life on all components can be 5000 hours. Of course, this feeling is based on the assumption that adequate test and development programs are incorporated into the design and initial production phases of the overall development of a particular machine.

Considering, further, the relatively high magnitude of the effect of limited life parts retirement on the maintenance cost, as evidenced by the statistical data which has been collected and presented herein, it can well be expected that adequate test and development programs will be incorporated into future helicopter airframe developments to extend the life of fatigue loaded components.

For this reason, the effect of increase in average limited life of components

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from 2000 hours to 5000 hours is shown for the rotor systems and transmissions and mechanical drives groups, where the statistical information has indicated the most serious maintenance cost penalties due to low limited life.

4. Correlation of Overhaul Period and Fatigue Life with Maintenance Cost

With the effects of power loading on overhaul period and fatigue life on limited life parts replacement cost available, it is necessary to correlate these detail cost changes with the overall maintenance cost for the particular group under consideration.

As was mentioned previously, the only groups in which the "power loading effect" was considered were engines and transmissions and drives. Effect of fatigue life change was investigated and is presented for rotor systems group and for transmissions and drives group. The methods used in developing the adjusted cost curves for 5000 hour component service life and power loading variation are discussed below.

Figure 4 on the following page presents a more detailed breakdown of the statistical cost data, already presented in Figure 2, for the engines, rotors, and transmissions and mechanical drives groups.

The table presents a summary of flight line labor, flight line material, overhaul labor, overhaul material and limited life parts material as percentages of total group cost or of total labor or total material cost for the particular group involved. These are related to the % normal rated power in cruise and overhaul period by use of Figure 3, and the net effects of percent NRP and limited life parts are shown as percentages of the cost found from the statistical study of currently operating helicopters. These new trends are shown in the set of figures included in Part D of this report section.

Figure 5, on Pages 20 and 21, is a general nomogram permitting the determination of percent NRP, overhaul period, and unit maintenance cost per lb/hour, for any combination of cruise speed, disk loading, equivalent parasite flat plate area per pound gross weight (A_{p0}/W), and power loading. The left hand side of Figure 5 relates cruise speed to percent NRP for any given disk loading and A_{p0}/W , and the right hand side in turn relates percent NRP to overhaul period and finally, to unit maintenance cost. It may be noted that increasing either the drag per pound (A_{p0}/W) or the disk loading results in higher percent NRP in cruise at a given speed for a fixed power loading, and also, lower power loadings reduce the percent NRP for a given A_{p0}/W , disk loading, and cruise speed. Usually, the determination of cruise speed is based on maximum miles per pound of fuel, but, of course, the maximum speed limited by rotor compressibility and/or tip stall cannot be exceeded. Turbine SFC characteristics, however, are such that turbine-powered helicopters in general cruise at higher speeds than reciprocating engine-powered helicopters in order to achieve maximum miles per pound of fuel.

On the right hand side of Figure 5 the relationship between overhaul period

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DETAIL BREAKDOWN OF STATISTICAL MAINTENANCE COST DATA

From Figure 3																	
System Group	Power Loading	Crude Power KW	Average Overhaul Period	Average Limited Life	\$ Line Labor Cost to Total Maint Cost	\$ Line Labor Cost to Total Labor Cost	\$ Line Mat'l Cost to Total Maint Cost	\$ Line Mat'l Cost to Total Labor Cost	\$ Overhaul Labor Cost to Total Maint Cost	\$ Overhaul Labor Cost to Total Labor Cost	\$ Overhaul Mat'l Cost to Total Maint Cost	\$ Overhaul Mat'l Cost to Total Labor Cost	\$ Limit. 125 Parts Cost to Total Maint Cost	\$ Limit. 125 Parts Cost to Total Labor Cost	\$ Present Total Cost	\$ Present Mat'l Cost	\$ Present Labor Cost
ENGINES	12	40	600	2000	19.2	10.0	10.4	20.0	28.8	60.0	41.6	80.0	--	--	100	100	100
	11	75	700	5000					24.8	51.6	15.6	68.8	--	--	90.2	89.8	91.6
	10	70	800						21.6	45.0	31.7	60.0	--	--	82.4	50.0	85.0
	9	65	900						17.3	40.2	21.7	53.6	--	--	76.8	73.6	80.2
	8	60	1000						17.3	36.0	25.0	48.0	--	--	71.7	65.0	76.0
	7	55	1100						15.6	32.4	22.5	43.2	--	--	67.7	63.2	72.4
MOTOR SYSTEMS	6	50	1200						14.4	30.0	20.8	40.0	--	--	64.8	50.0	70.0
	12	80	450	2000	8.0	40.0	4.0	5.0	12.0	60.0	32.0	40.0	44.0	55.0	100	100	100
TRANSMISSIONS AND MECHANICAL DRIVES	12	80	450	5000	--	--	--	--	--	--	--	--	17.6	22.0	73.6	67.0	100
	12	80	450	2000	7.2	30.0	3.8	5.0	16.8	70.0	57.0	75.0	15.2	20.0	100	100	100
	11	75	550	5000	5.9	24.5	3.1	4.1	13.7	57.3	46.6	61.4	6.1	8.0	75.4	73.5	81.8
	10	70	650		5.0	20.8	2.6	3.5	11.6	47.4	39.4	51.9			64.7	63.4	69.2
	9	65	750		4.3	19.0	2.3	3.0	10.1	43.7	34.2	45.0			57.0	56.0	60.0
	8	60	850		3.6	15.7	2.0	2.6	9.9	37.3	30.2	39.7			51.0	50.3	52.9
	7	55	950		3.4	14.2	1.8	2.4	8.0	33.2	27.0	35.6			46.3	46.0	47.4
	6	50	1050		3.1	12.9	1.6	2.1	7.2	30.0	24.5	32.2			42.5	42.3	42.9

FIGURE 4

K_1 and K_2 are the two principal stresses (or principal strains) in the plane of the crack. K_1 is the maximum principal stress (or strain) and K_2 is the minimum principal stress (or strain). K_1 and K_2 are related to the applied stress σ and the crack opening displacement δ by the following equations:

Principal Stresses
 (or Strains) in the Plane
 of the Crack

$$K_1/K_2 = 1 \pm \sqrt{1 + 4\sigma/\delta}$$

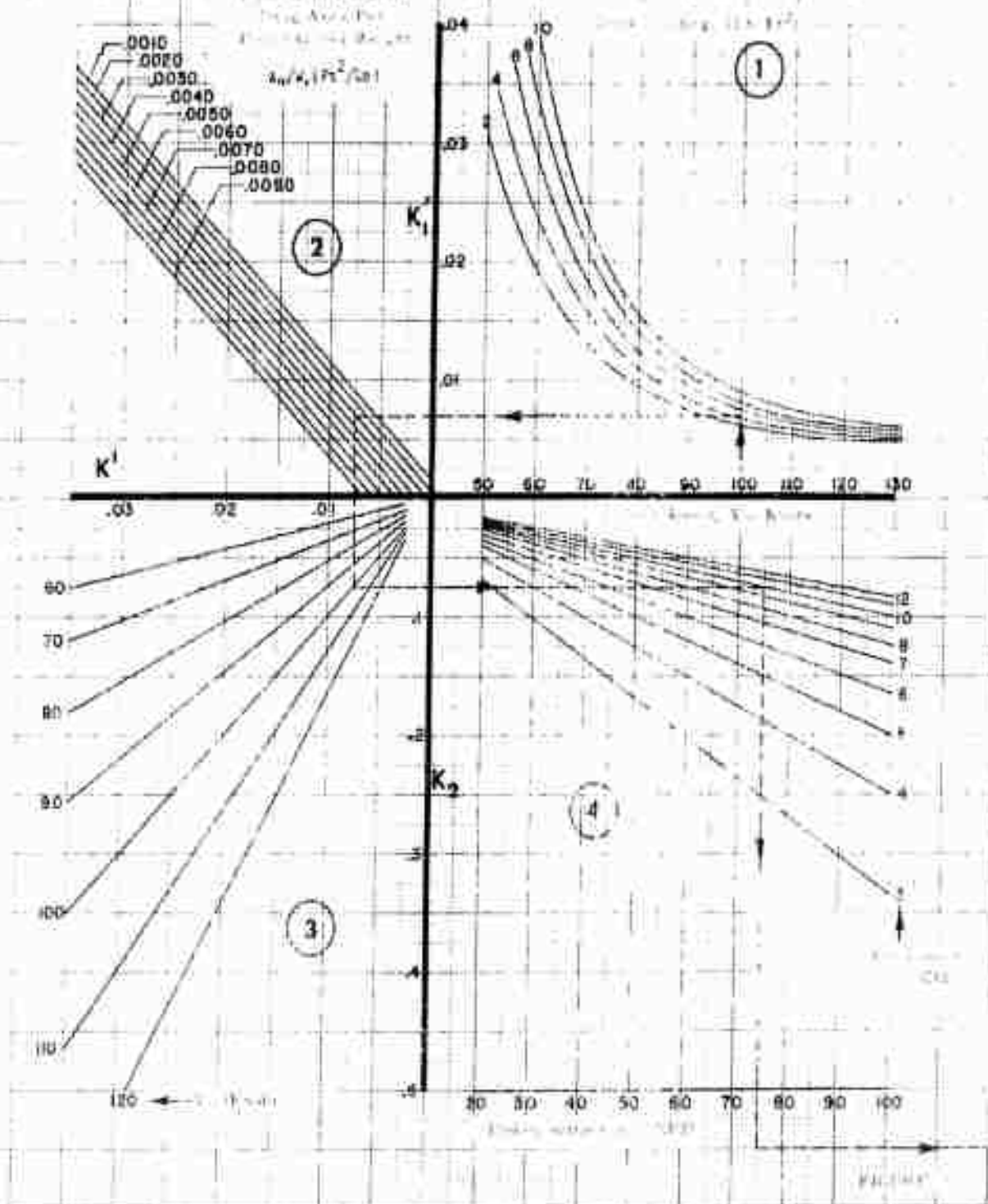


Figure 1. The effect of the concentration of the reagent on the rate of the reaction.

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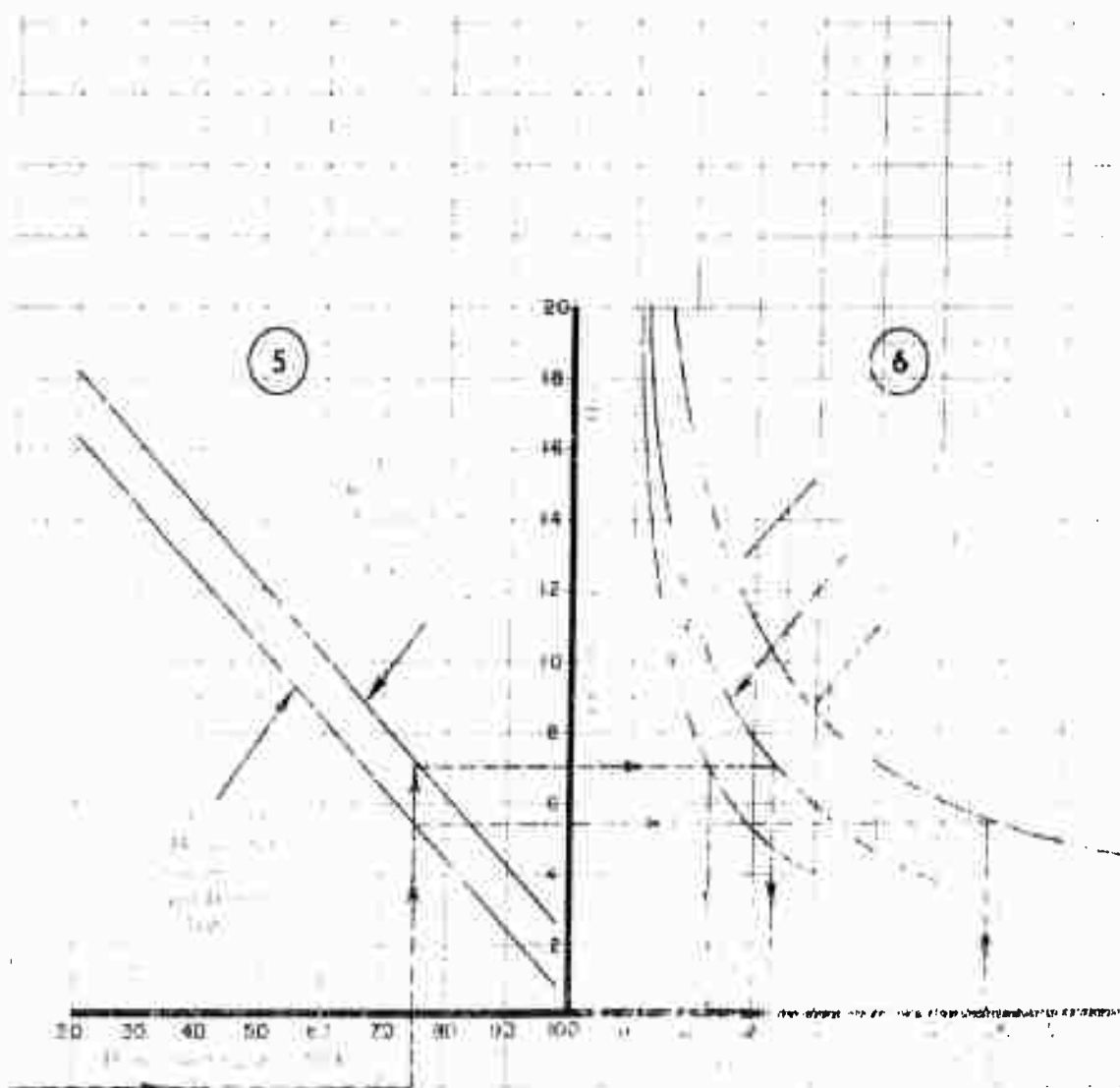


Figure 1. The effect of the concentration of the reagent on the rate of the reaction.

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and percent NRP for turbines is shown to be the same as for the reciprocating engines; however, the "locate" point was established for turbines as 1000 hour overhaul period for design cruise power setting of 60 percent NRP. This was done upon the advice of airline and engine manufacturer personnel.

5. Power Plant Data Extension

In order to allow the maintenance cost evaluation of designs having power plant types other than reciprocating engines, data is presented on the estimated total maintenance costs of turbine installations and ramjets. Consideration of the cost analysis of pressure jet and tip turbine-powered configurations will also be discussed herein.

Turbines

Although the available cost data on turbine engines is limited, many airlines have made investigations into such matters, and the engine manufacturers have indicated their thoughts also on the subject of turbine maintenance cost. Some actual operating data of British European Airlines was collected, together with cost information from the above mentioned sources, to arrive at the trends presented under "Engines" under Part D of this section. Considering operation at least five years hence, the general feeling was to indicate, for the helicopter, a 1000 hour overhaul period for a 60 percent normal rated power cruise condition. This coincides exactly with the reciprocating data also shown in Figure 5. The extensions of the basic data to other percentages of NRP in cruise was made in the same manner as indicated previously for the reciprocating power plants by consideration of the overhaul cost percentage of the total.

Ramjets

The maintenance cost curve presented for ramjet power plants is based on past Hiller experience with the now CAA certified 8RJ2B Ramjet engine used as the main power plants on the H-32 and HOE Military helicopters. A 1000 hour overhaul period has been assumed, and it has been further assumed that the total overhaul cost is represented by the first cost of the engine. This is brought about by the consideration that it will probably be cheaper to replace a production ramjet, due for inspection and overhaul after extended use, rather than to pay for the labor and material to overhaul it.

A sufficient number of hours on a number of different helicopter ramjet installations have not been completed to date to consider any power loading effect on this type of power plant. If the effect is present, it would probably tend to be quite small. This would be due to the fact that no moving parts are involved in ramjet operation, and the critical wear conditions found in other types of power plants do not exist.

Consideration of Pressure-Jet Types of Propulsion

Since no maintenance cost data is available on this type of propulsion device,

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only an intuitive approach can be made. Since all pressure-jet systems have either a reciprocating or a turbine engine to drive the compressor stage, the major portion of the power plant maintenance cost can be obtained directly from the reciprocating or turbine data presented in this report. Since the remainder of the power plant (ducting, tip burners, etc.) becomes part of the rotor system, its maintenance cost will be reflected by a higher percentage rotor systems maintenance cost, due to the higher weight of the rotor system group in comparison to more conventional power plant types.

While the approach cannot be considered quantitatively accurate, it is believed that the overall effect on maintenance cost will be in the proper perspective if this system of power plant and rotor system cost estimation is adhered to.

Suggested Approach for Tip-Mounted Turbines

Since tip-mounted turbines have been proposed in both this country and in Great Britain for application to large transport helicopters, some consideration should be made here of their possible maintenance costs.

Since no successful application of the turbine to rotor tip operation is feasible until such a power plant is specifically developed for the high structural loadings involved in this type of installation, it is the feeling of power plant designers concerned with the problem that upon the successful development of such a turbine, its maintenance costs will be identical to those of the fixed installation turbine. This reasoning is based on the fact that although this type of engine will be a new design compared to what is now available in aircraft gas turbines, its operating parts will be essentially the same. This consideration, of course, will allow the use of the turbine maintenance cost data presented in this report when considering tip turbine maintenance cost evaluations.

D. Maintenance Cost Trends

1. Summary of Cost Trends Presented

On the following pages are presented the detail items of maintenance cost for all the component system groups. Total costs, material costs, labor costs, and labor hours are presented graphically to allow the cost analysis of helicopters of 70,000 lbs. empty weight or more.

2. List of Symbols and Abbreviations

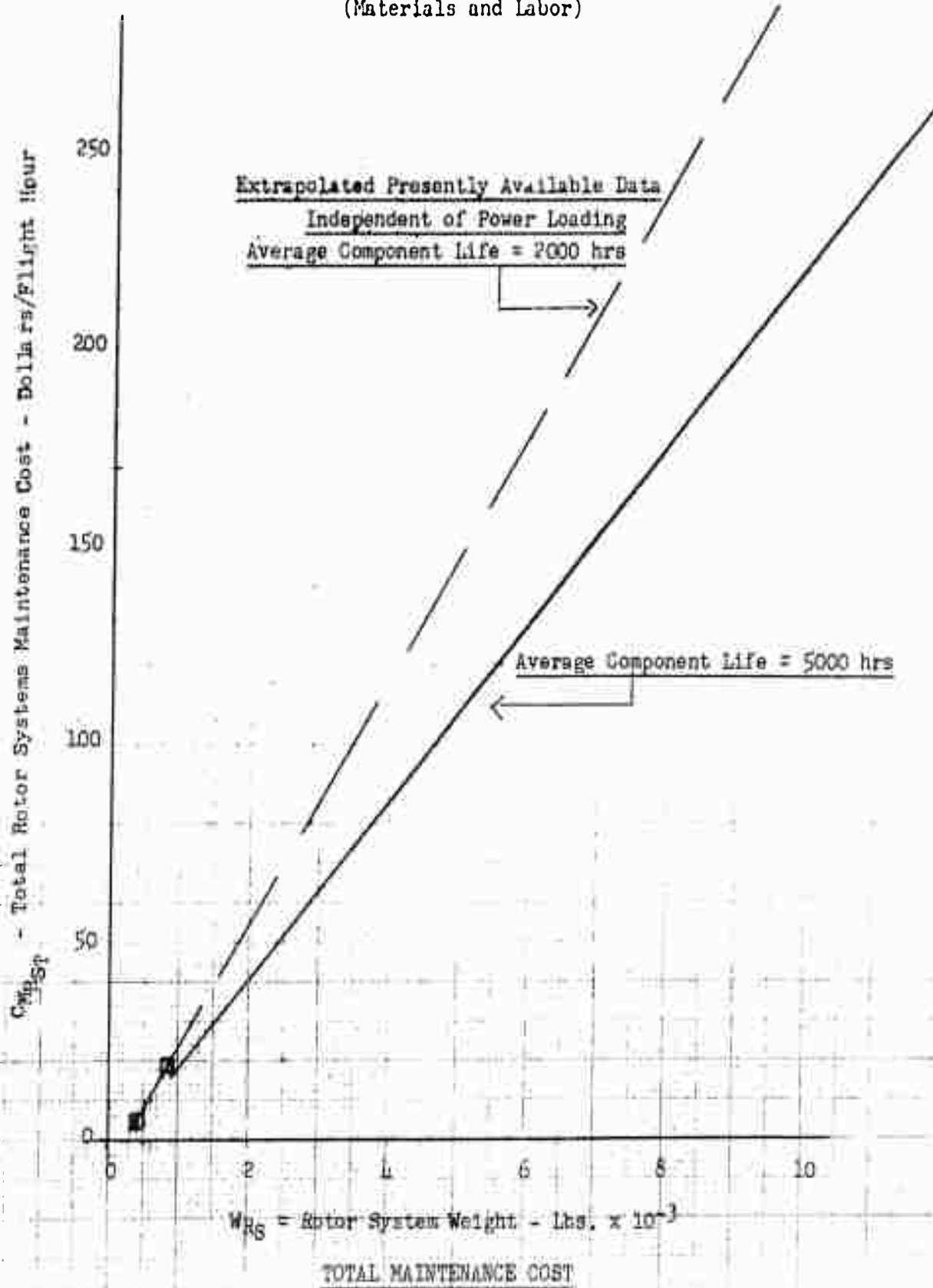
lp = Power Loading (pounds/BHP)
 NRP = Normal Rated Power
 OHP = Overhaul Period (Flight Hours)
 C_M = Cost of Maintenance

Subscripts

RS = Rotor System
 TD = Transmissions and Drives
 E = Engines
 A = Airframes
 O = Other
 T = Total
 M = Materials
 L = Labor

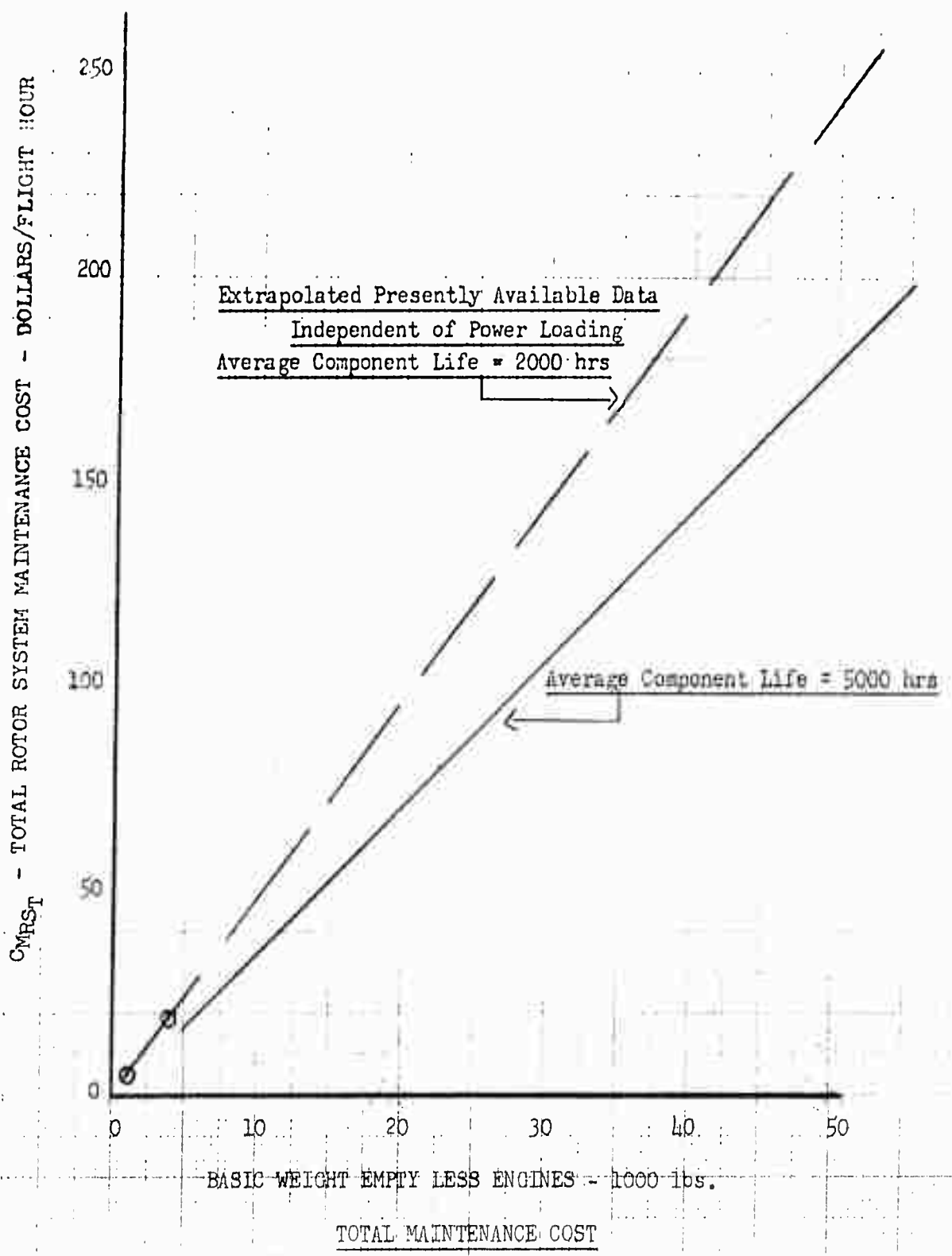
ROTOR SYSTEMS

Total Maintenance Cost
(Materials and Labor)



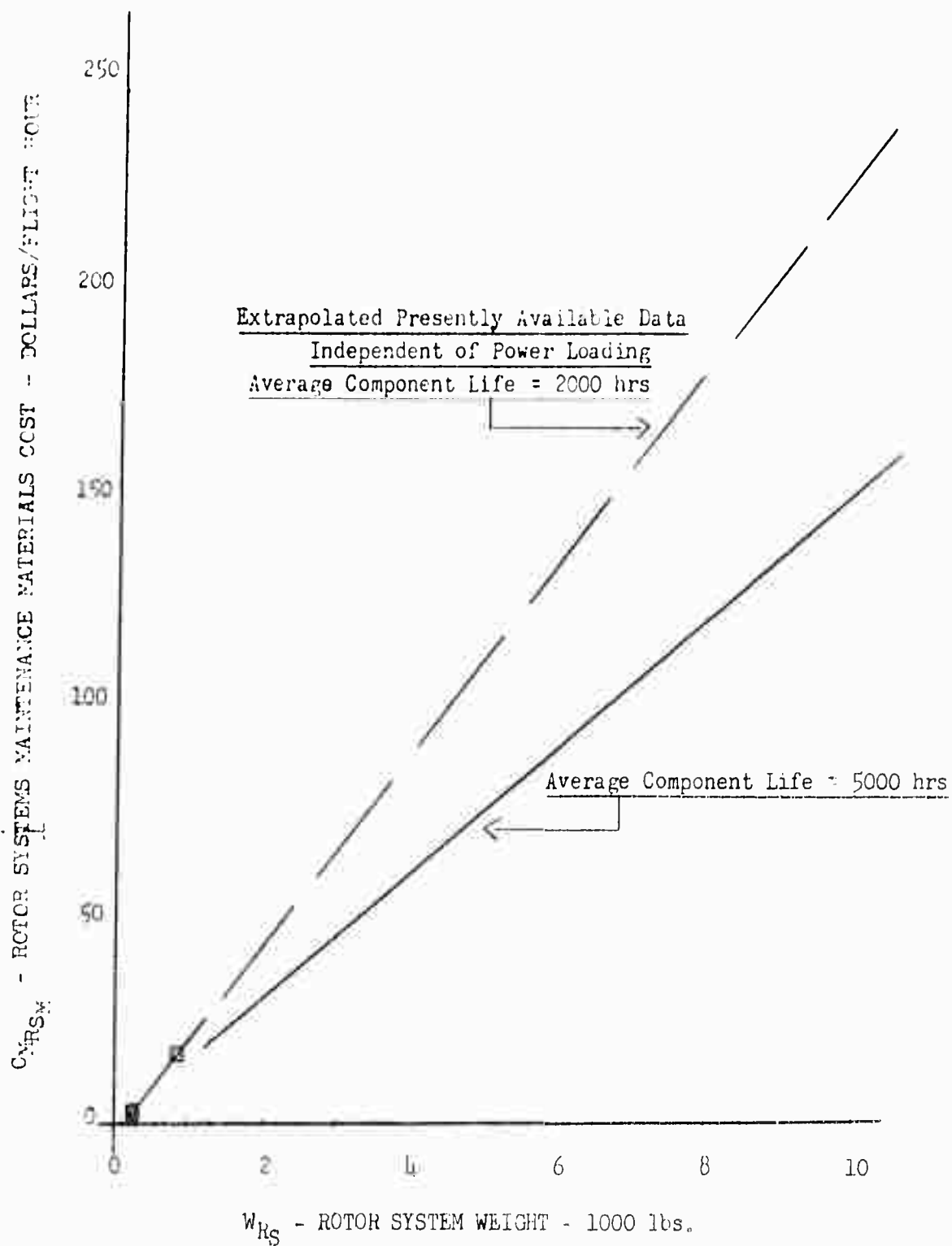
ROTOR SYSTEMS

Total Maintenance Cost
(Labor and Materials)



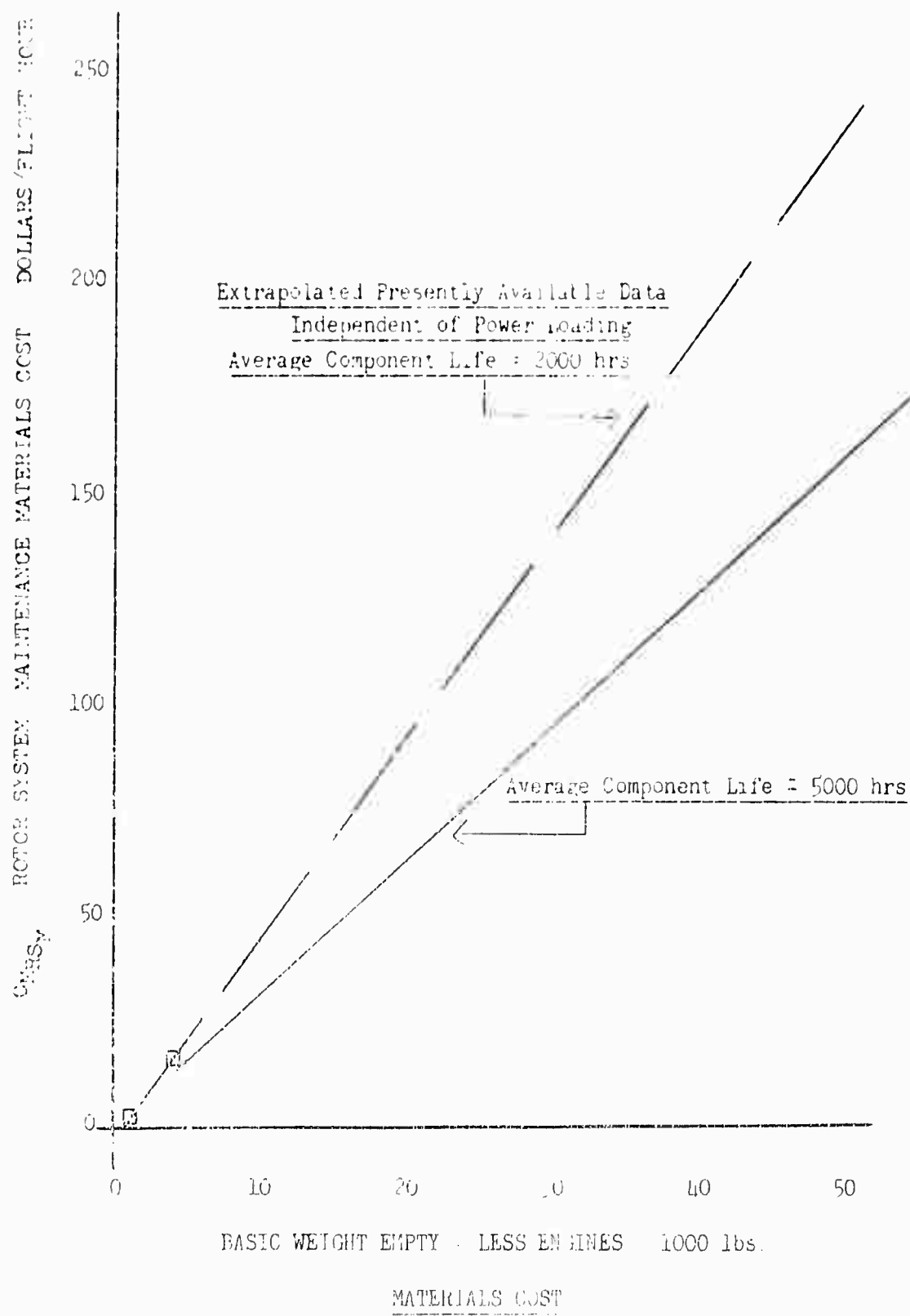
ROTOR SYSTEMS

Maintenance Materials Cost

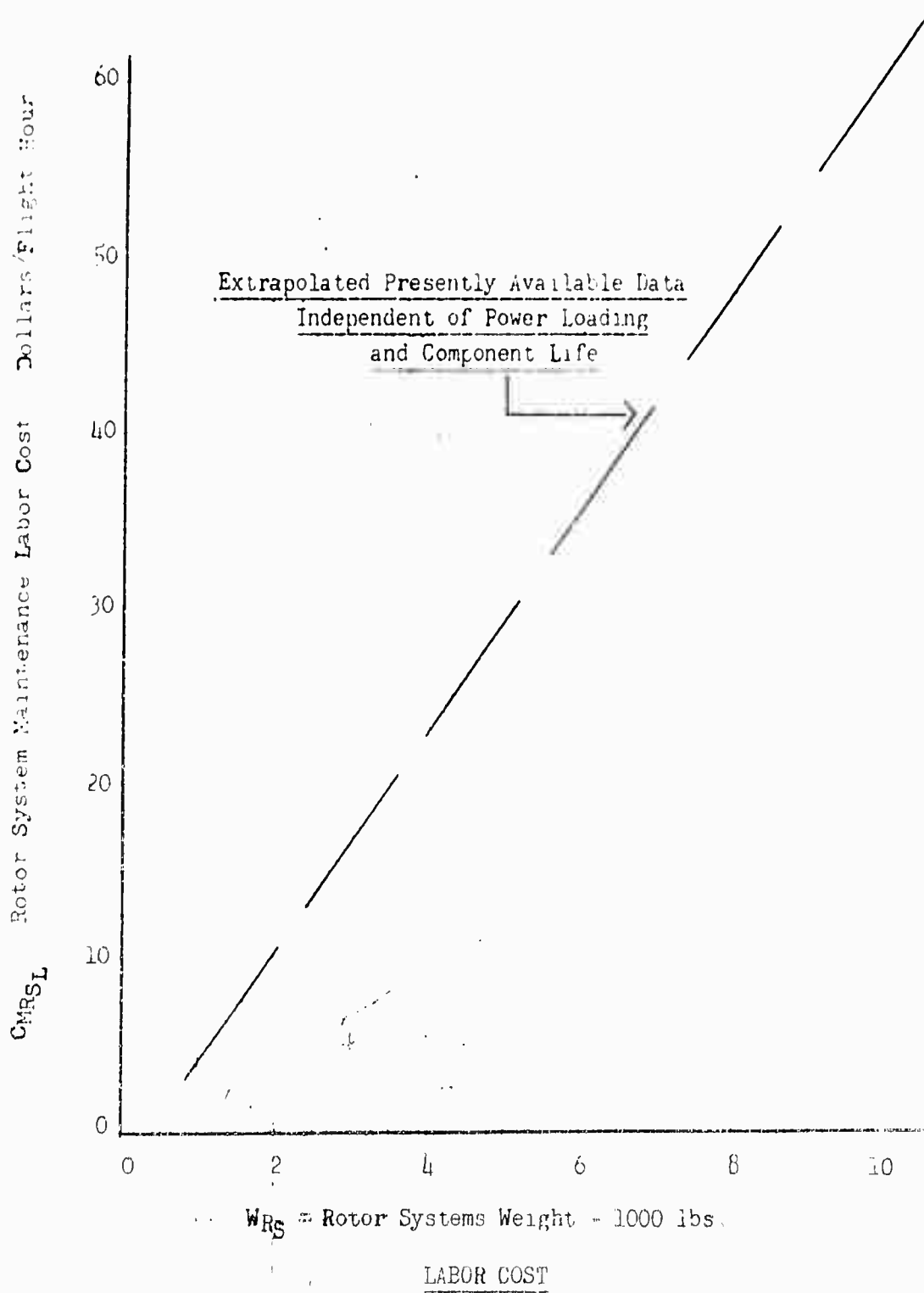


MATERIALS COST

U.S. Navy
Maintenance Materials Cost

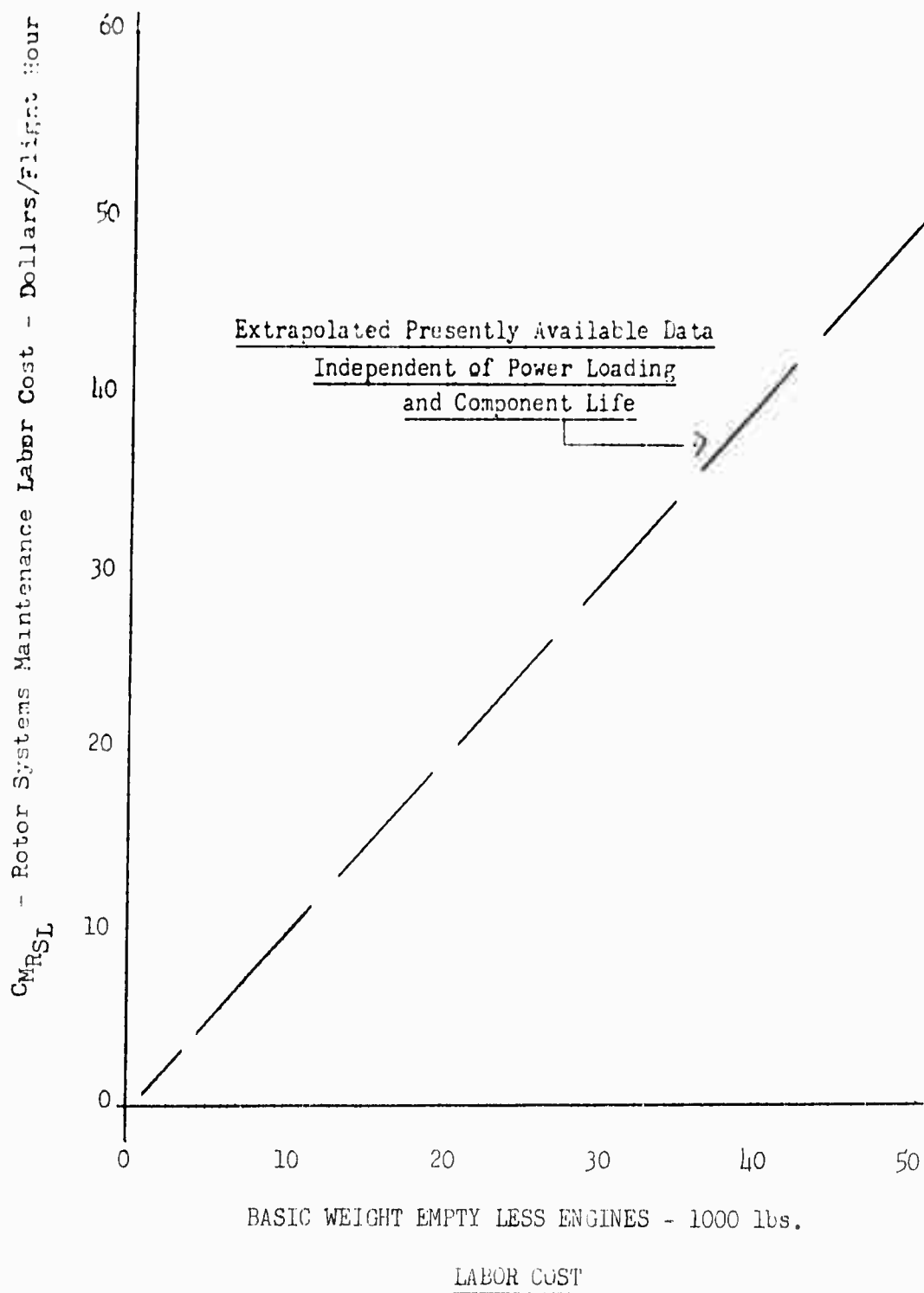


ROTOR SYSTEMS
Maintenance Labor Cost.



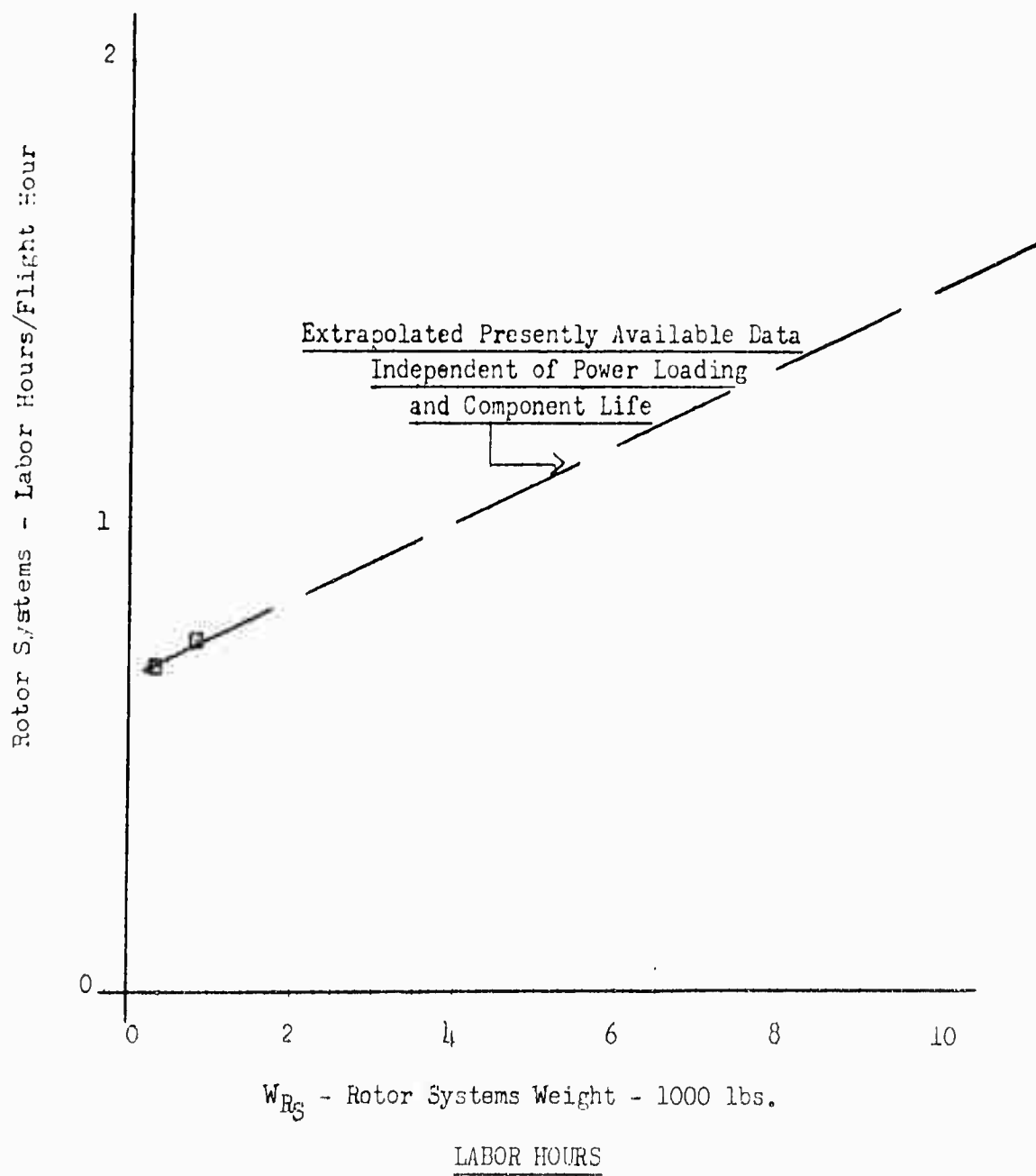
ROTOR SYSTEMS

Maintenance Labor Costs



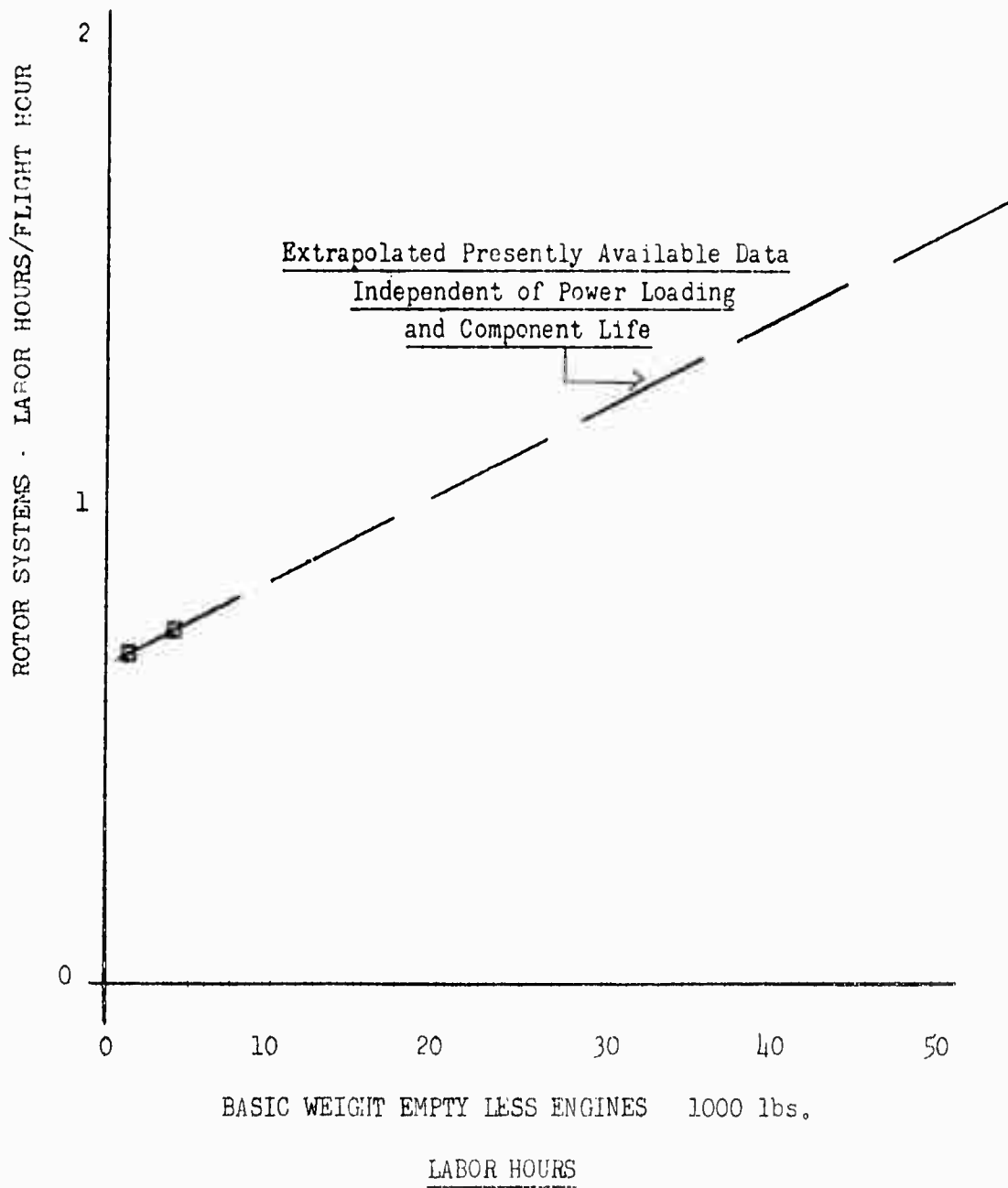
ROTOR SYSTEMS

Maintenance Labor Hours



ROTOR SYSTEMS

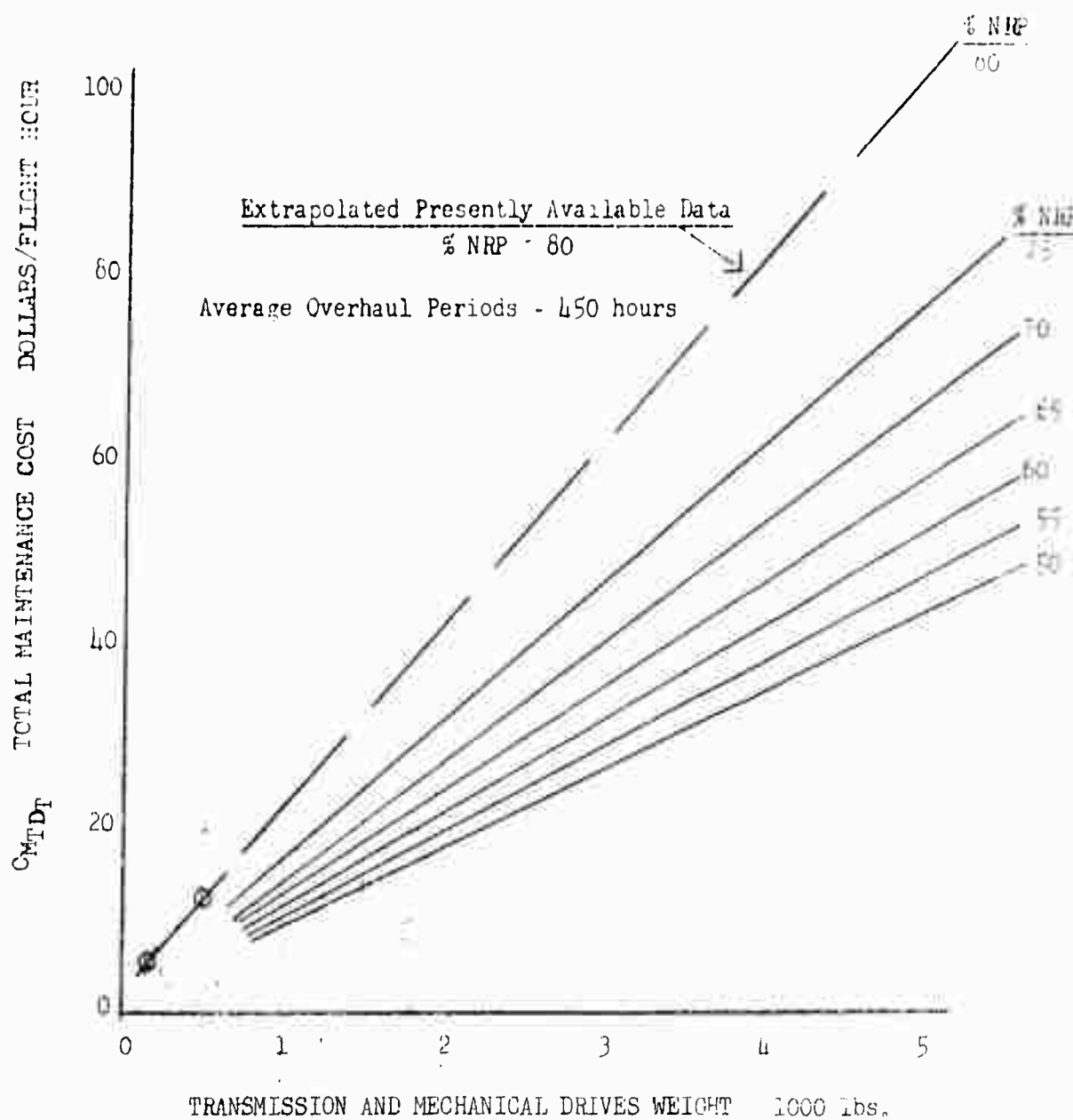
Maintenance Labor Hours



TRANSMISSIONS AND MECHANICAL DRIVES

Total Maintenance Cost

(Labor and Materials)

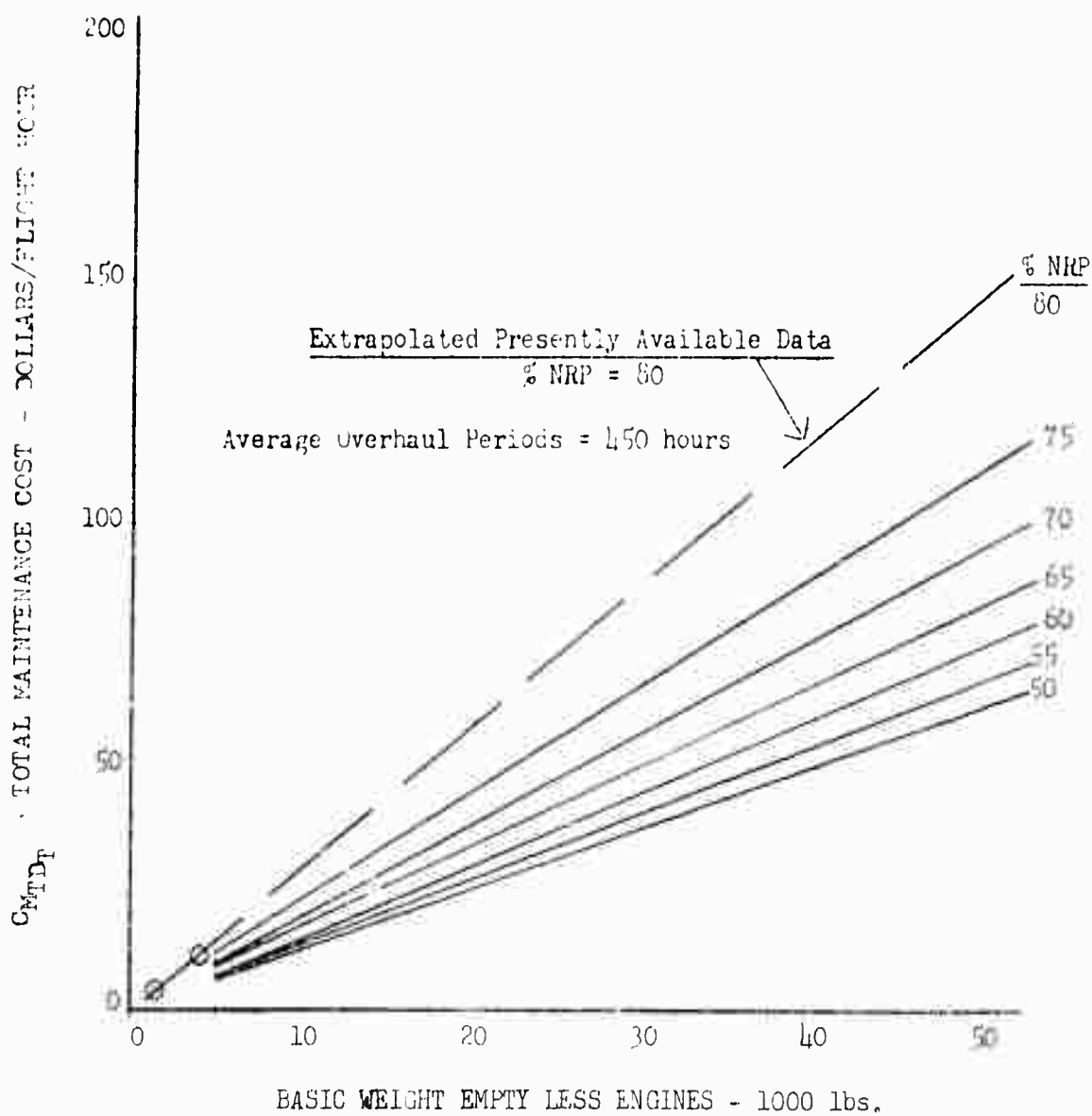


TOTAL MAINTENANCE COST

TRANSMISSIONS AND MECHANICAL DRIVES

Total Maintenance Cost

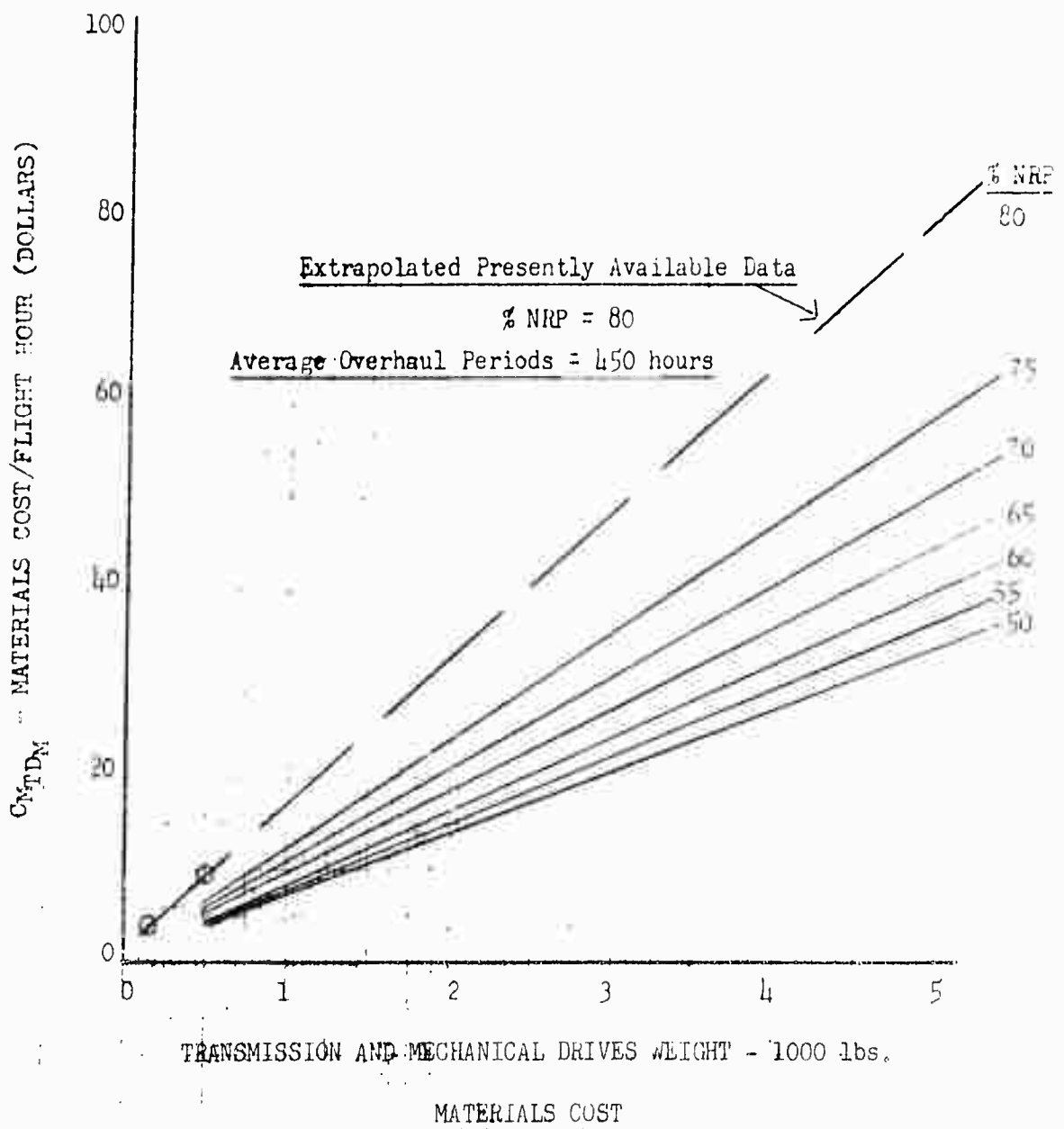
(labor and Materials)



TOTAL MAINTENANCE COST

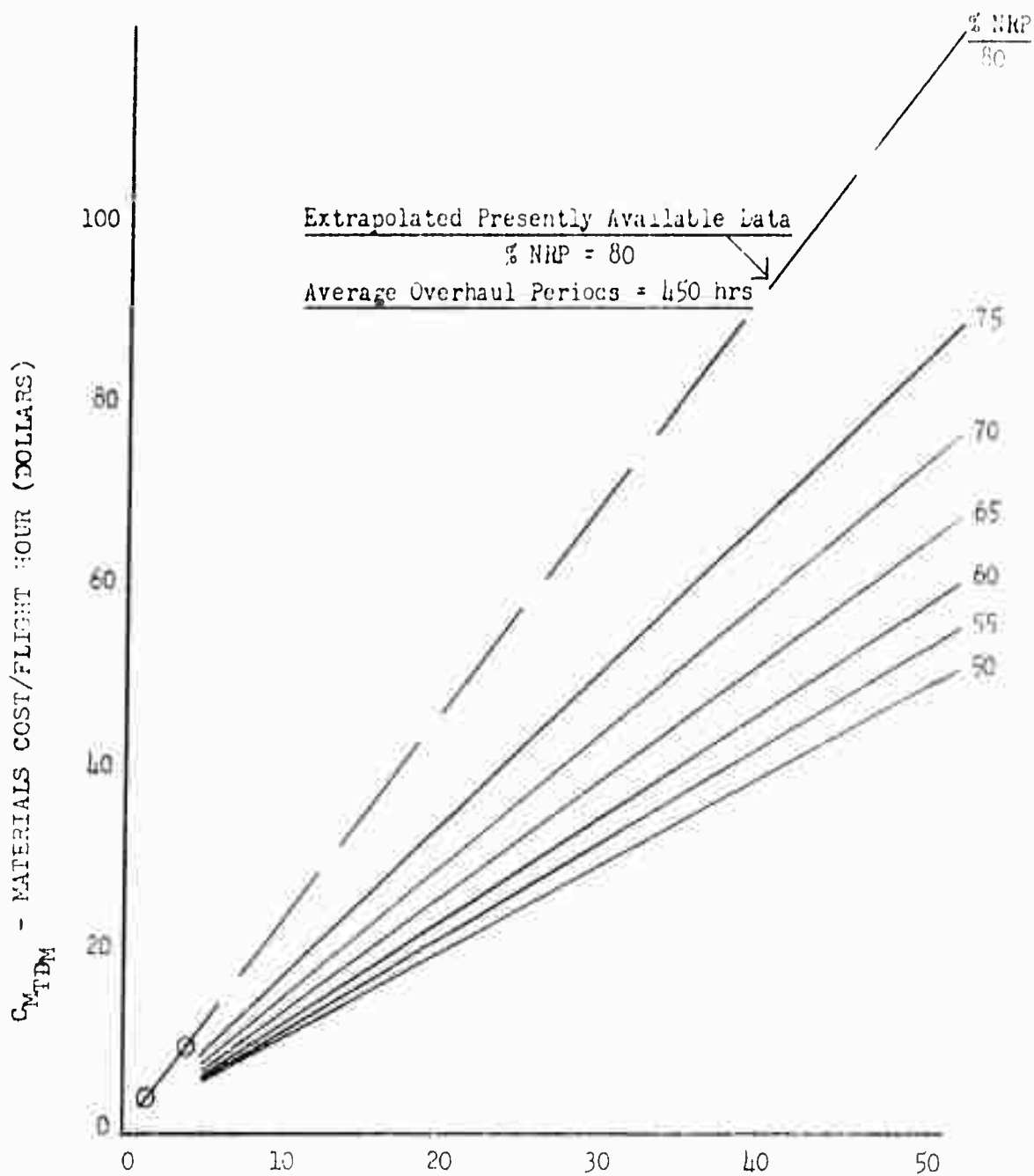
TRANSMISSIONS AND MECHANICAL DRIVES

Maintenance Materials Cost



TRANSMISSIONS AND MECHANICAL DRIVES

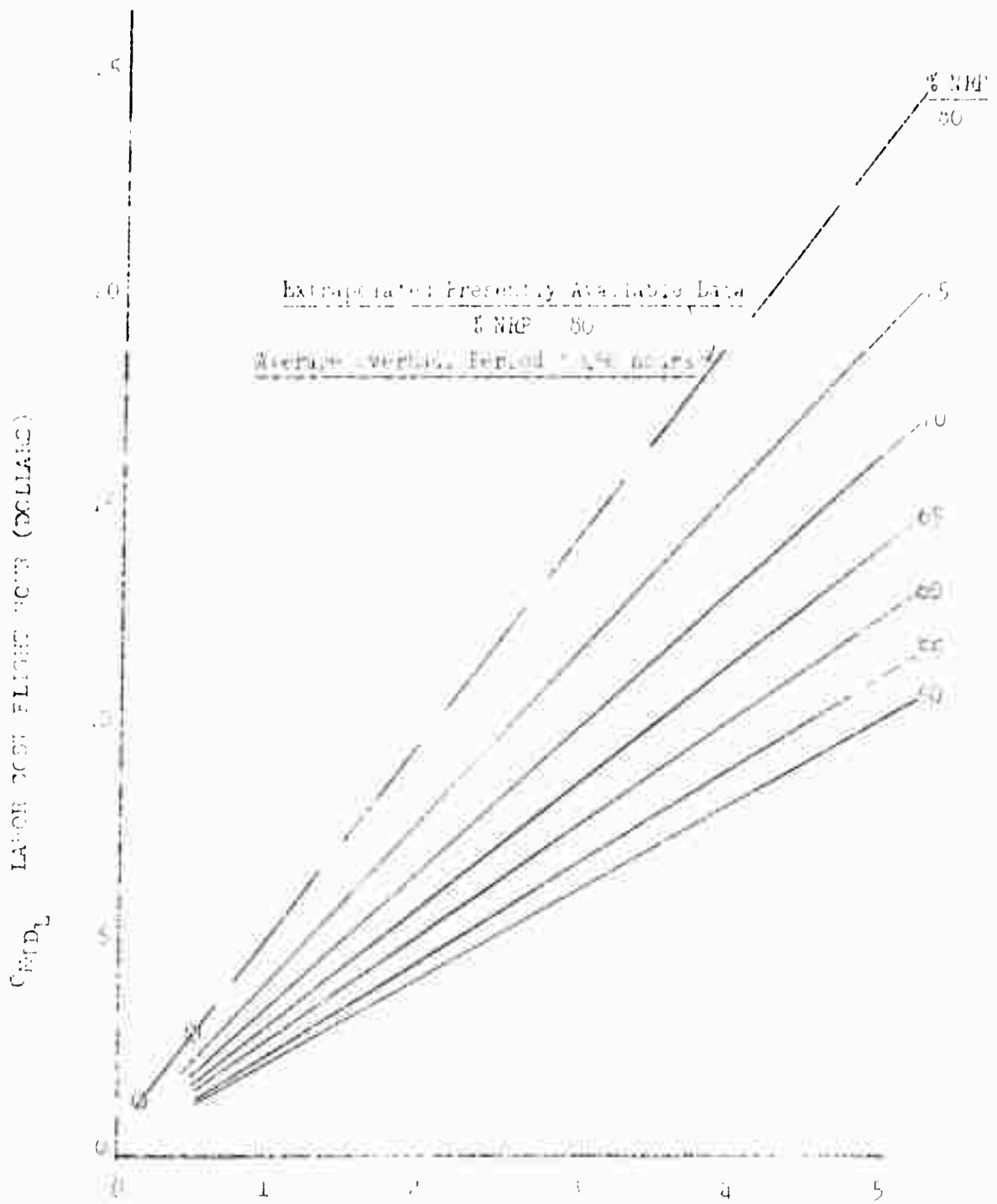
Maintenance Materials Cost



MATERIALS COST

TRANSMISSION AND MECHANICAL DRIVES

Maintenance Labor Cost

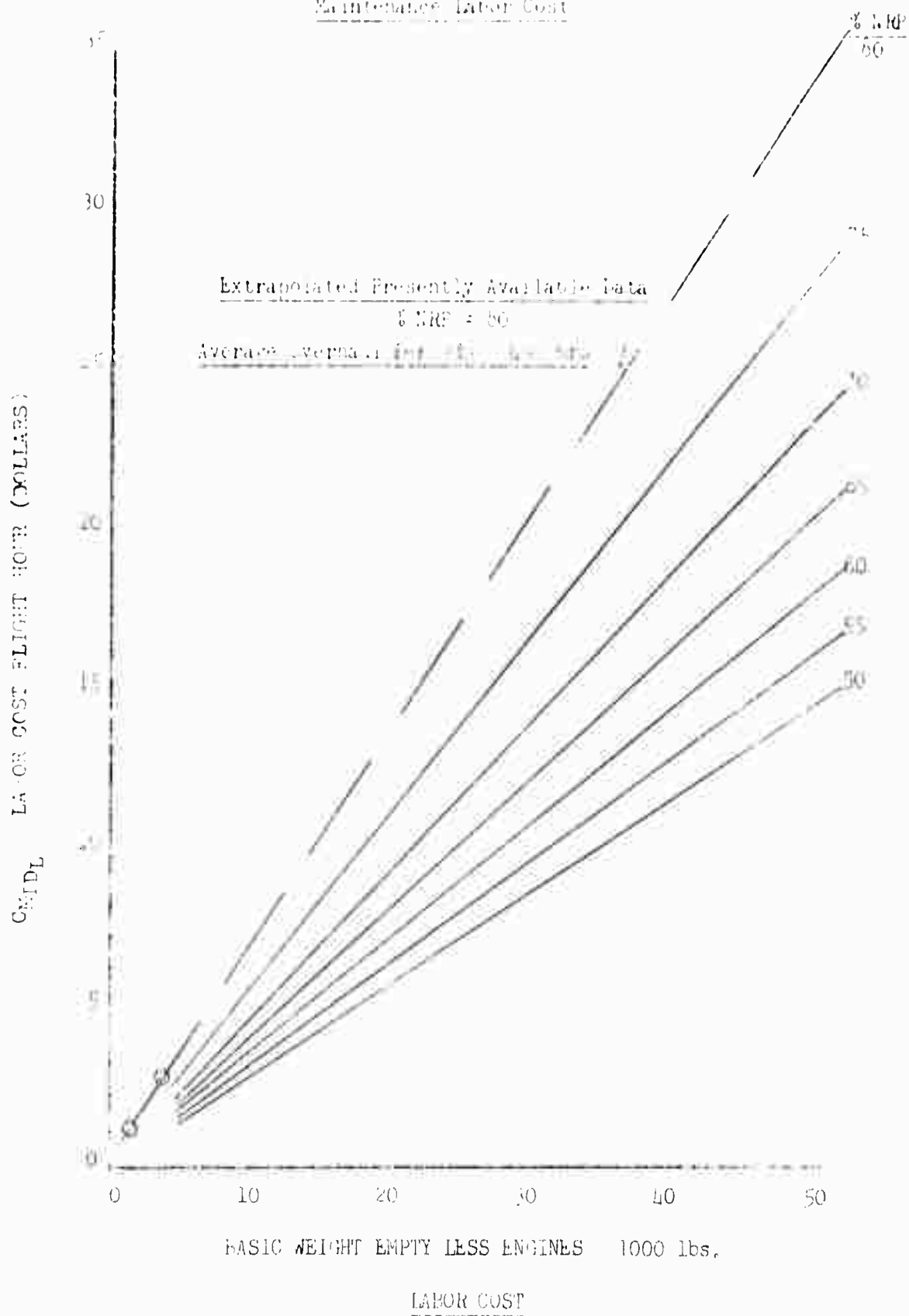


TRANSMISSION AND MECHANICAL DRIVES WEIGHT 1000 lbs.

LABOR COST

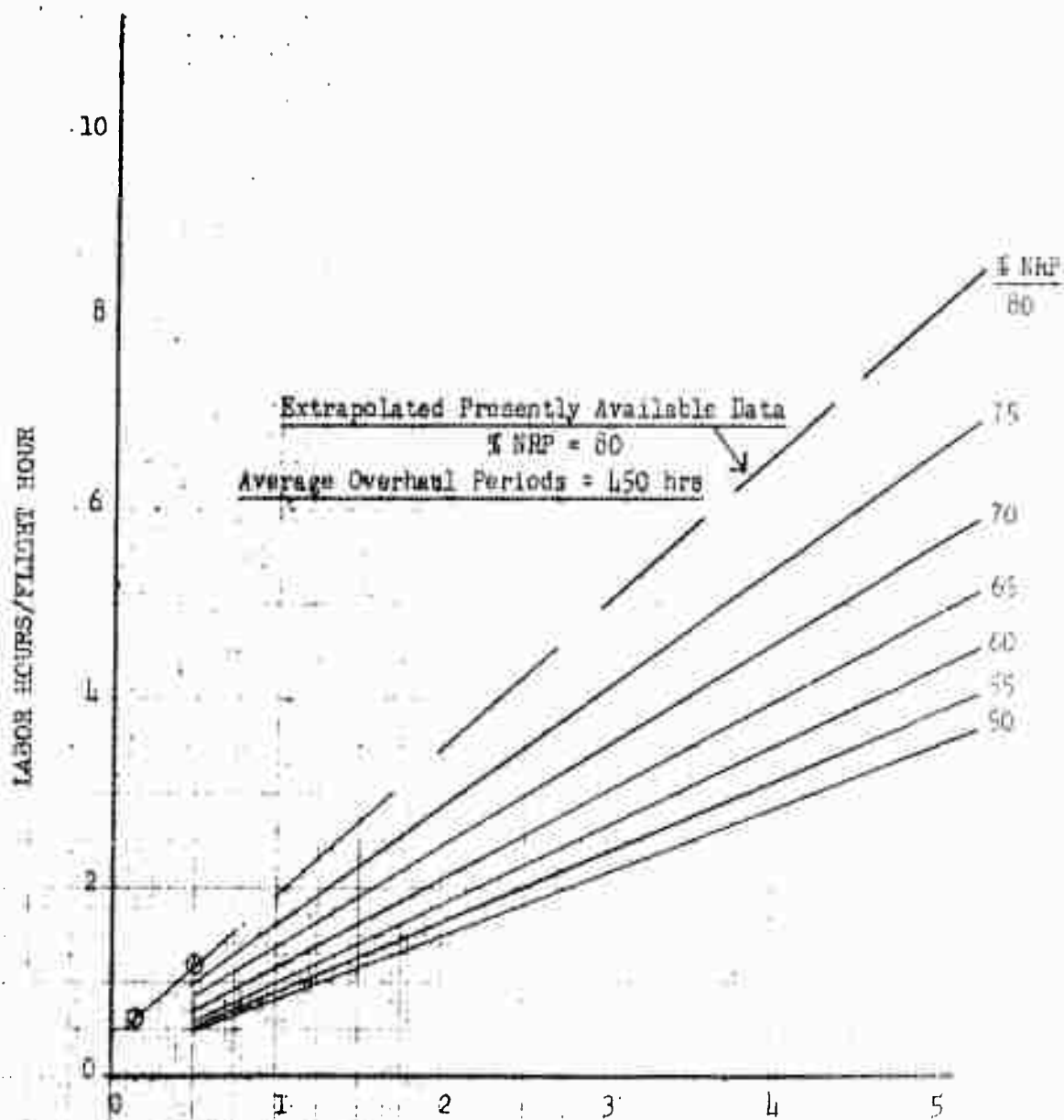
TRANSPORTATION AND MAINTENANCE COSTS

Maintenance Labor Cost



TRANSMISSIONS AND MECHANICAL DRIVES

Maintenance Labor Hours

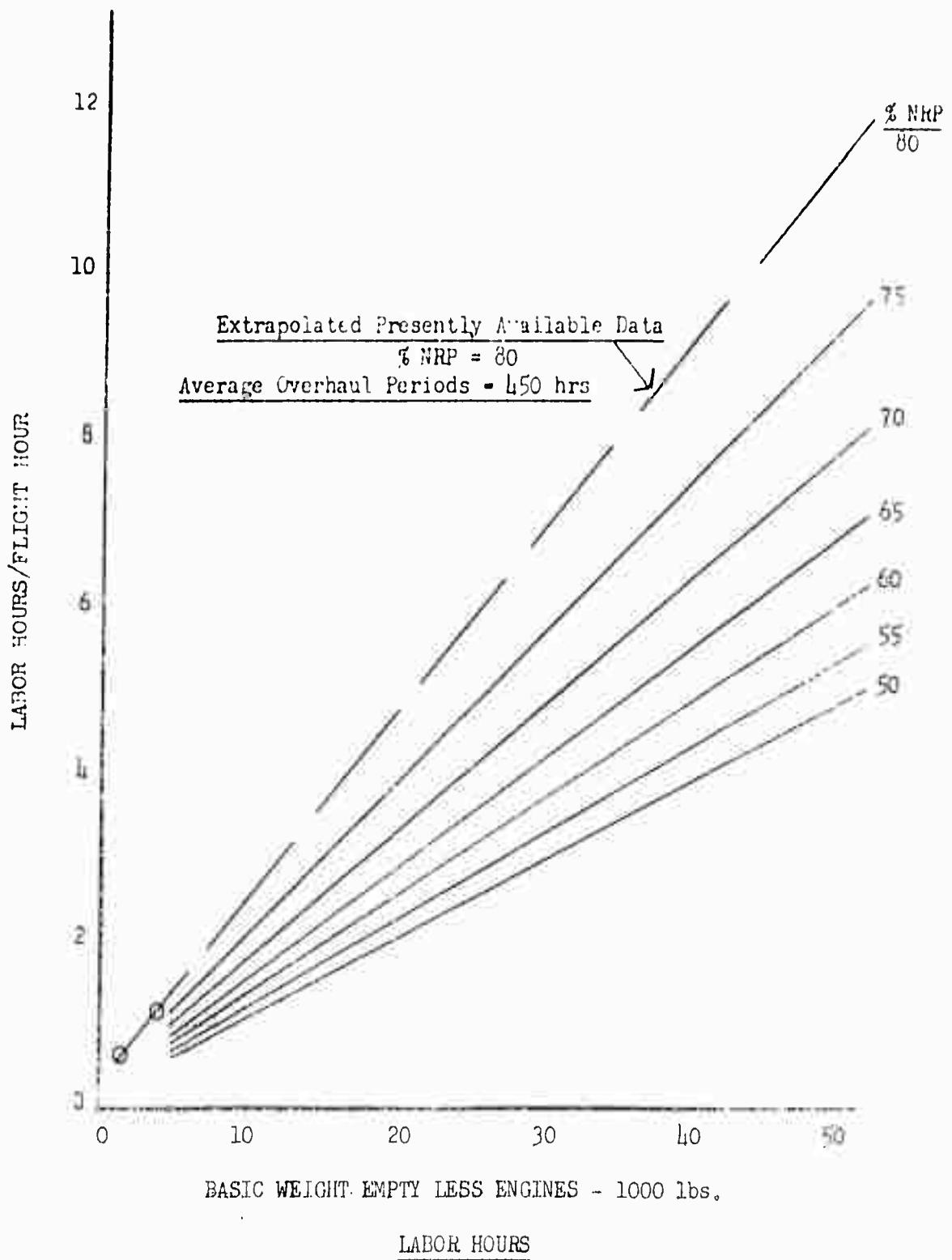


TRANSMISSIONS AND MECHANICAL DRIVES WEIGHT - 1000 lbs.

LABOR HOURS

TRANSMISSIONS AND MECHANICAL DRIVES

Maintenance Labor Hours

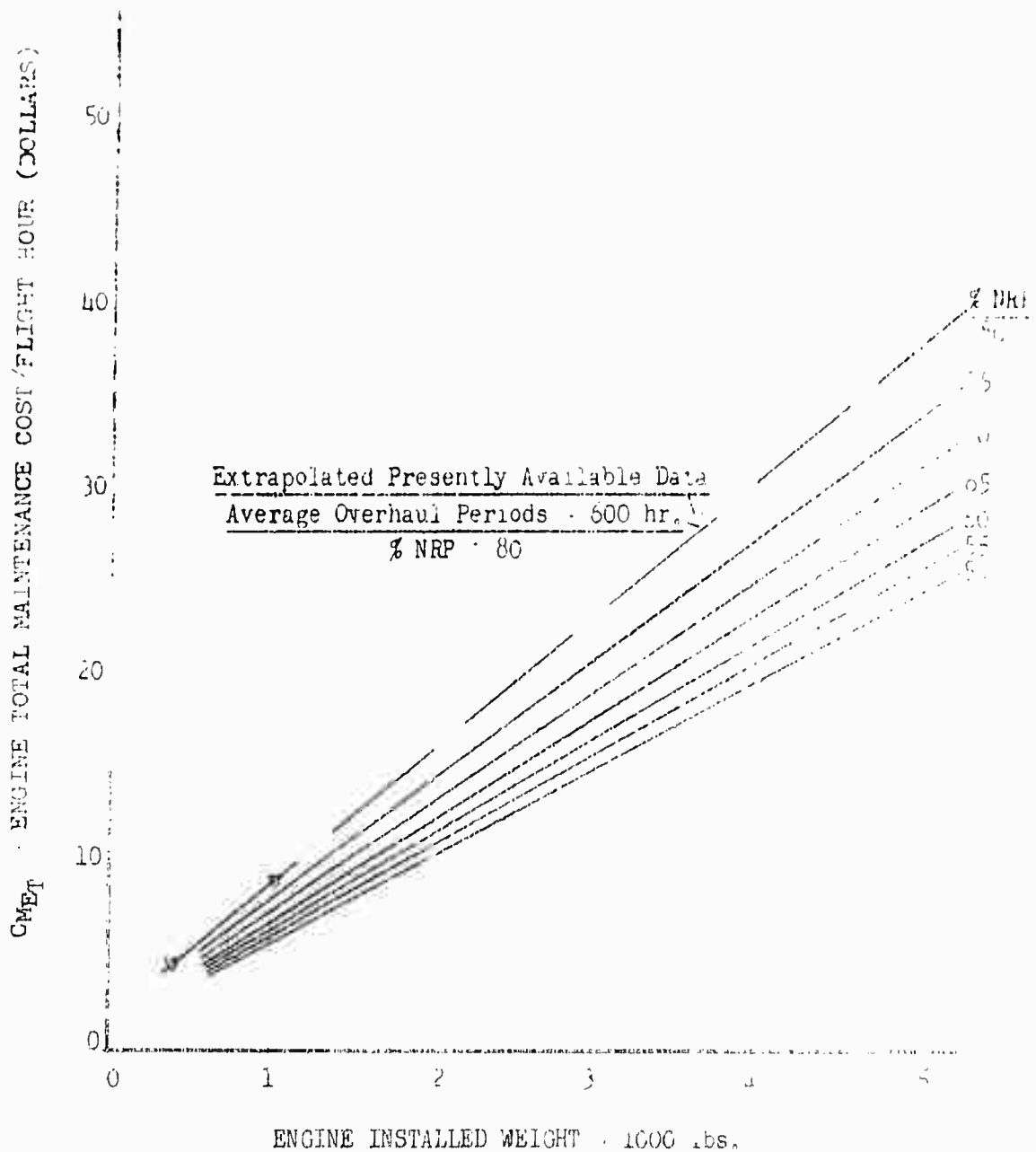


ENGINE

Total Maintenance Cost

(Labor and Materials)

(Reciprocating)

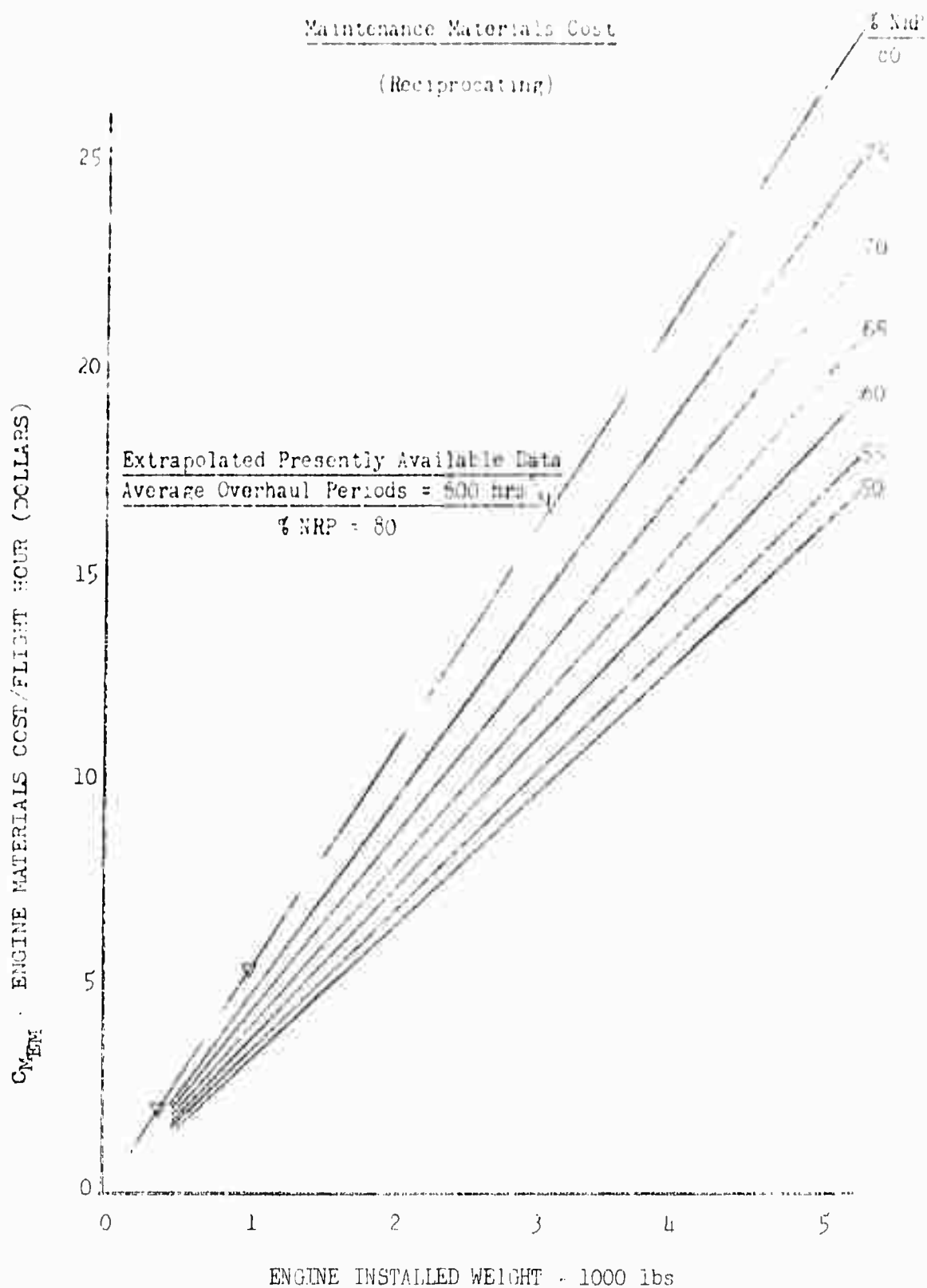


TOTAL MAINTENANCE COST

ENGINES

Maintenance Materials Cost

(Reciprocating)

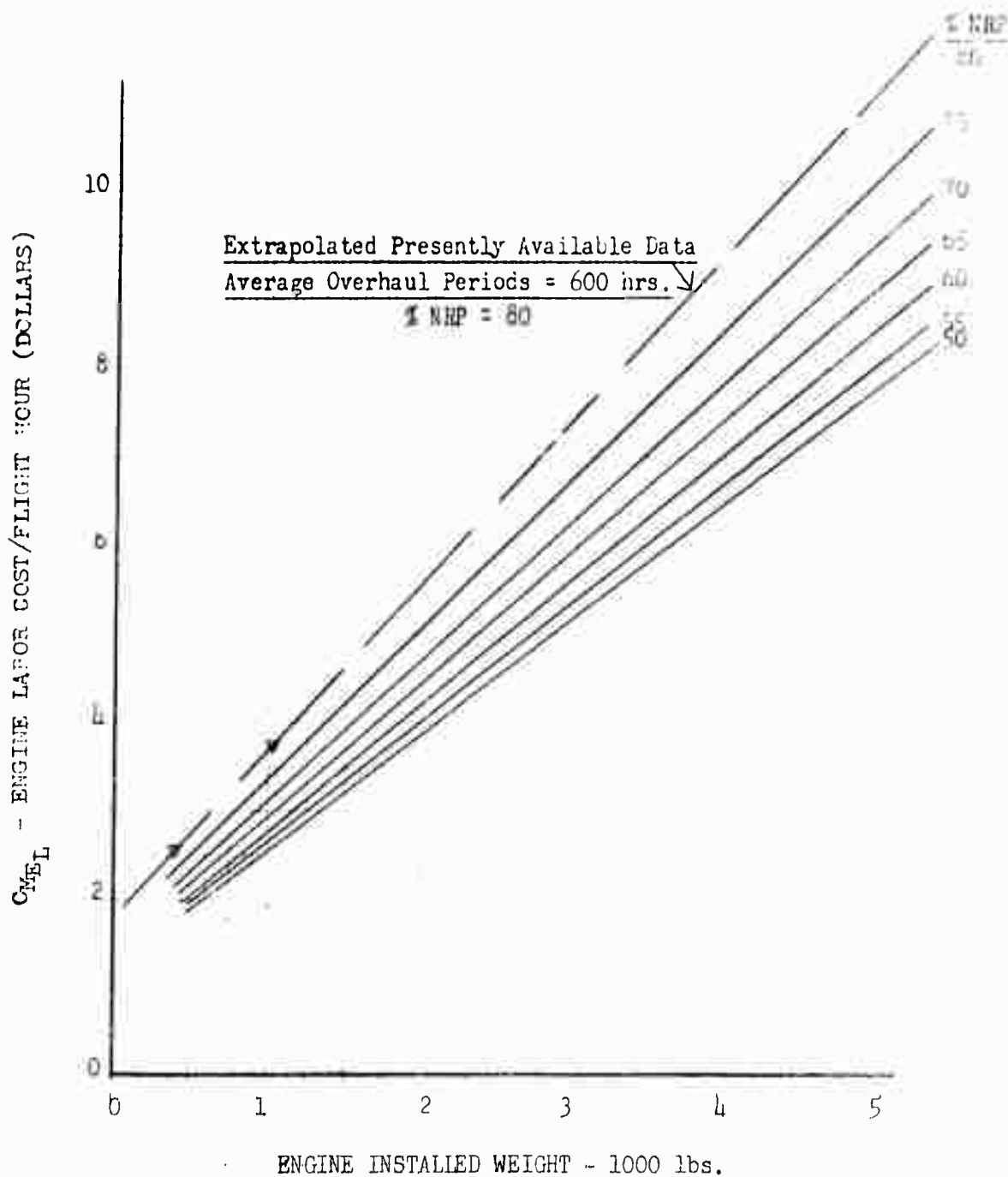


MATERIALS COST

ENGINE

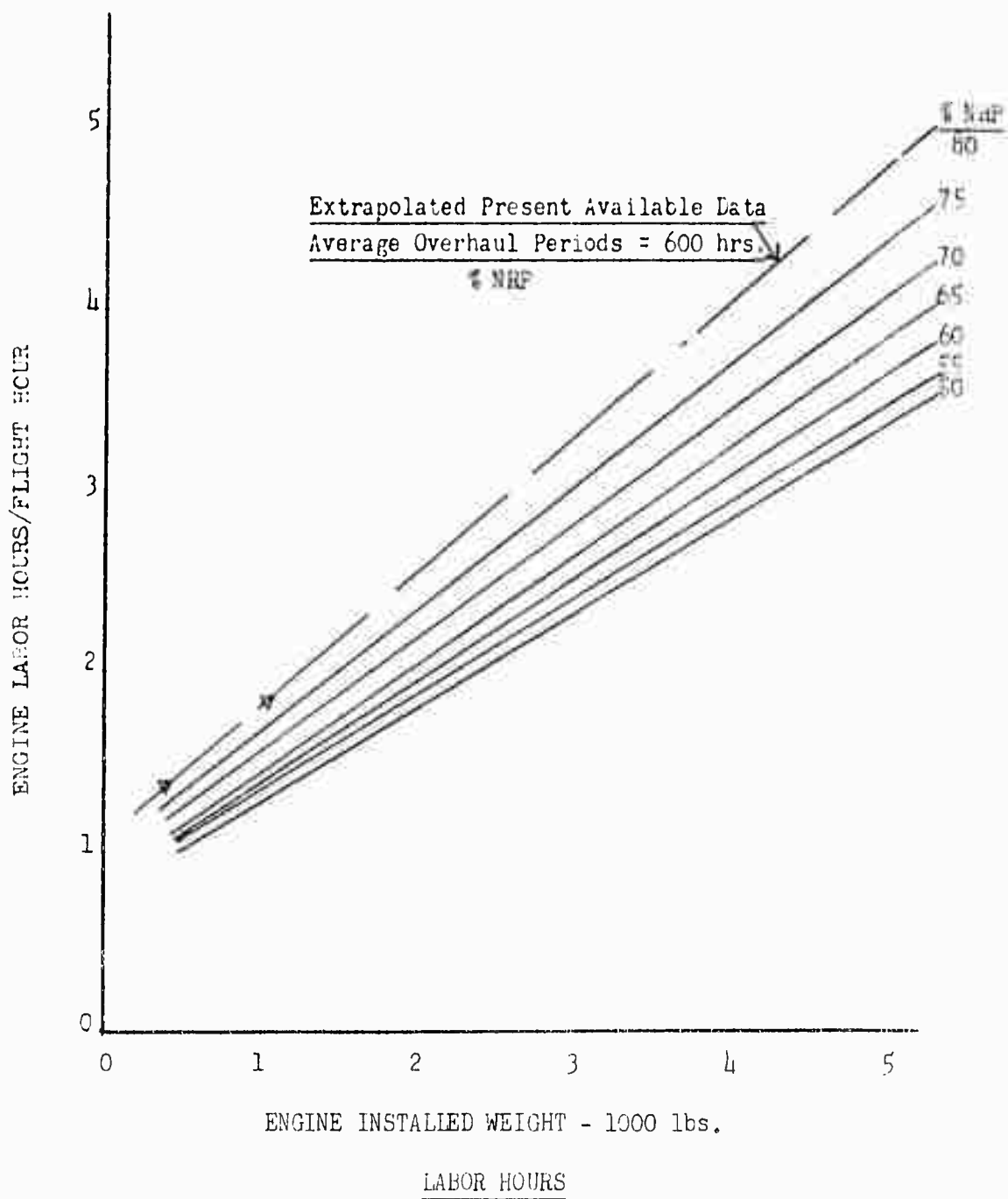
Maintenance Labor Cost

(Reciprocating)

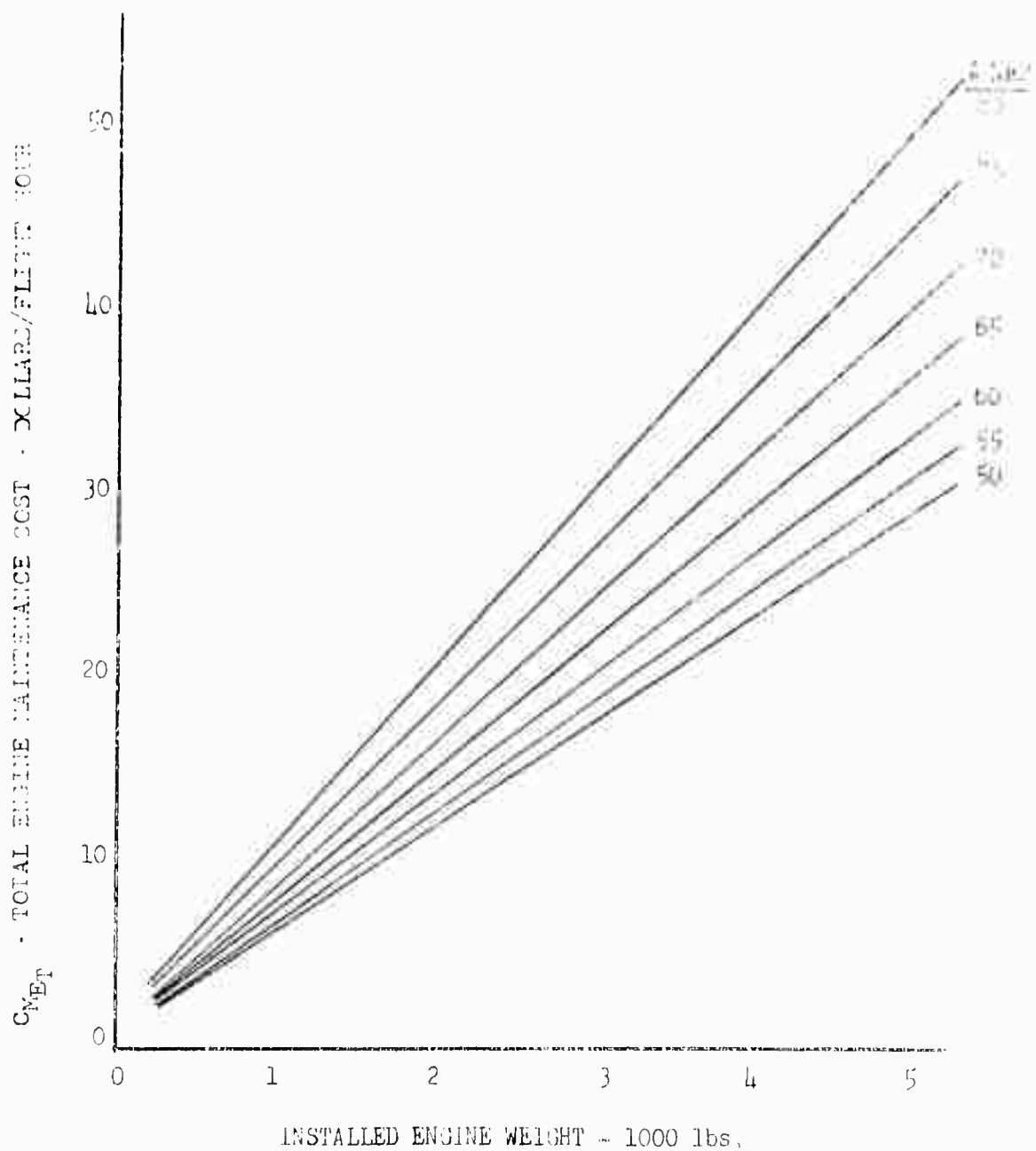


LABOR COST

ENGINE
Maintenance Labor Hours
(Reciprocating)



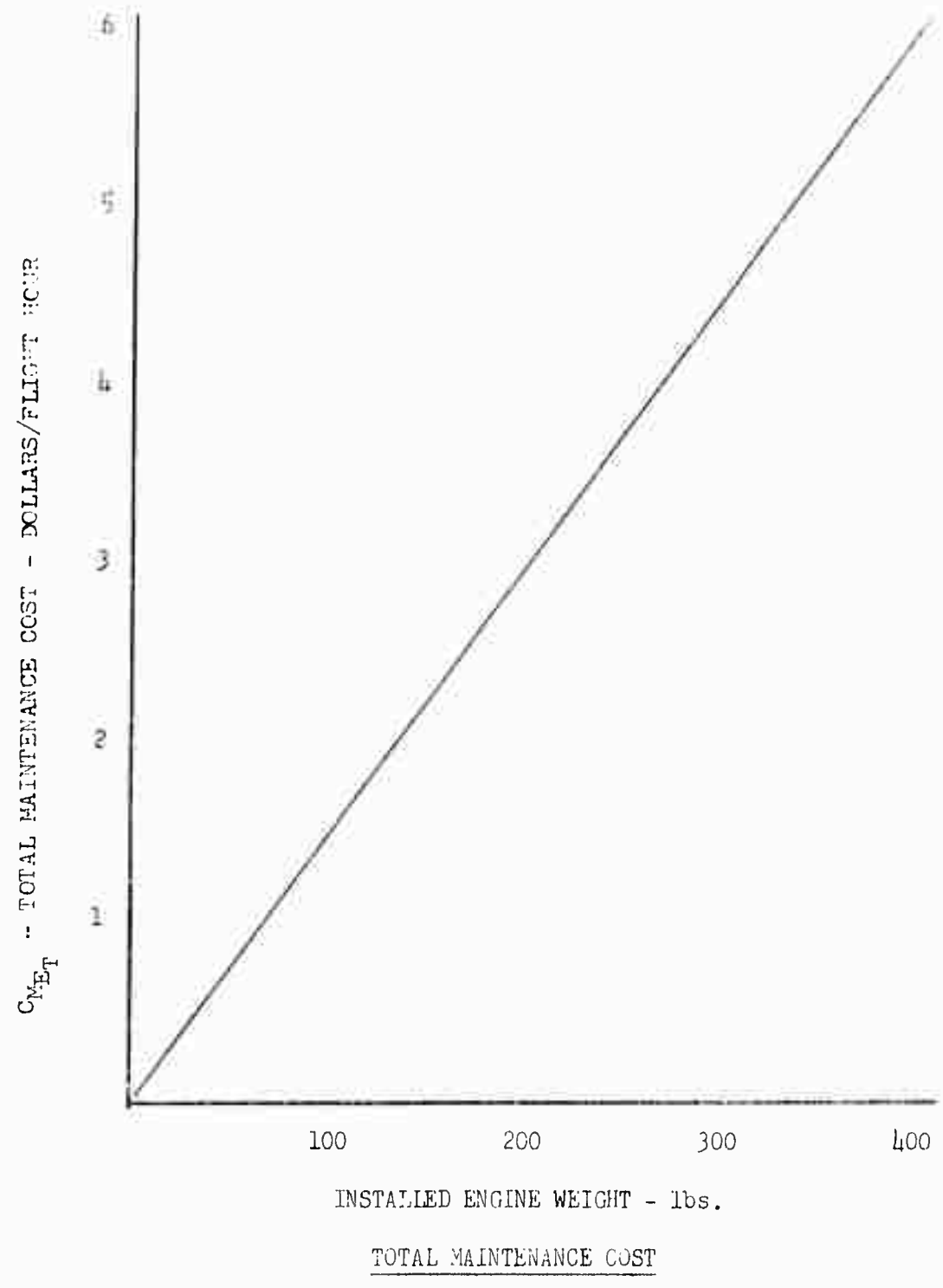
ENGINE
Total Maintenance Cost
 (Turbines)



ENGINES

Total Maintenance Cost

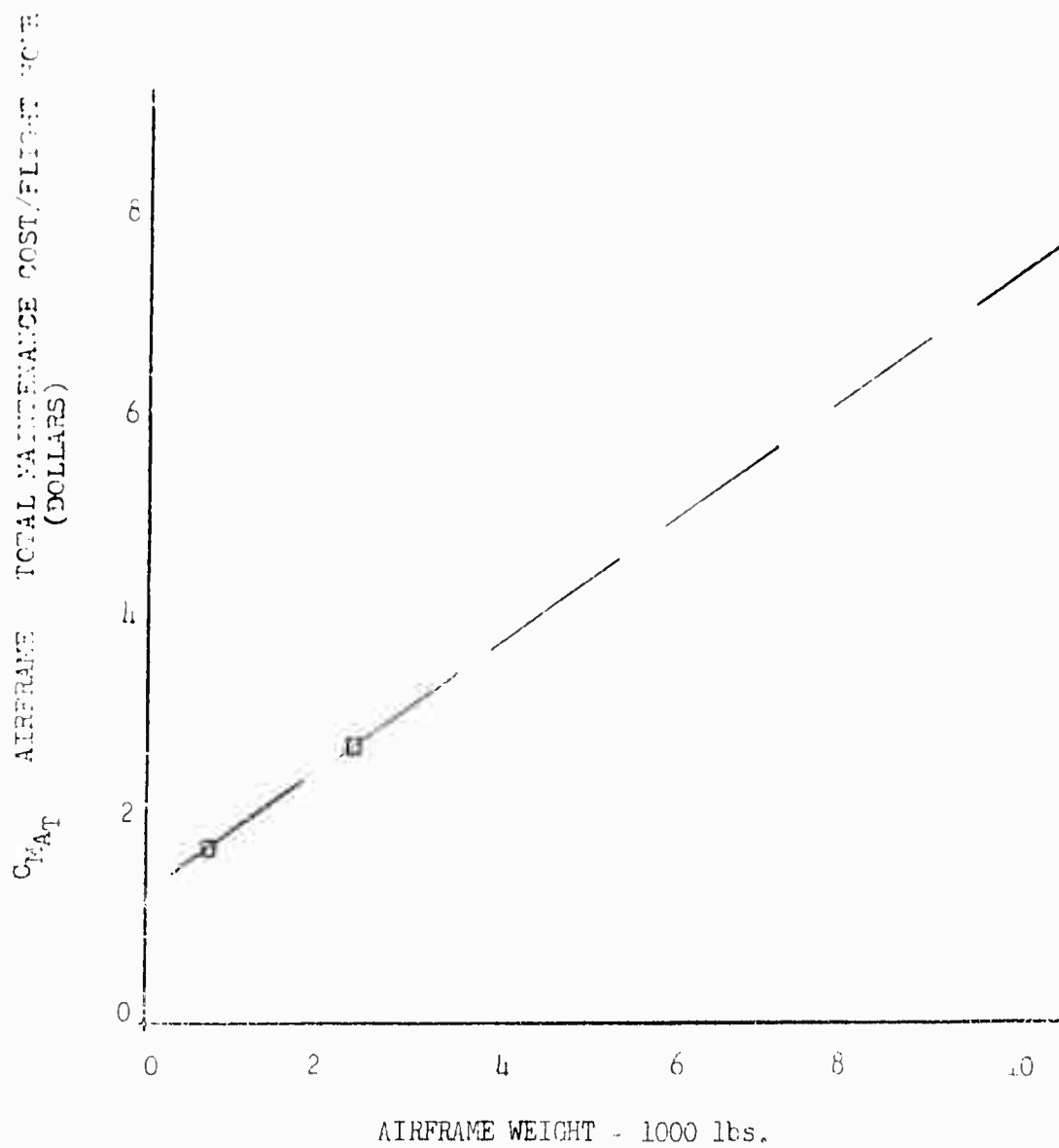
(Ram Jets)



AIRFRAME

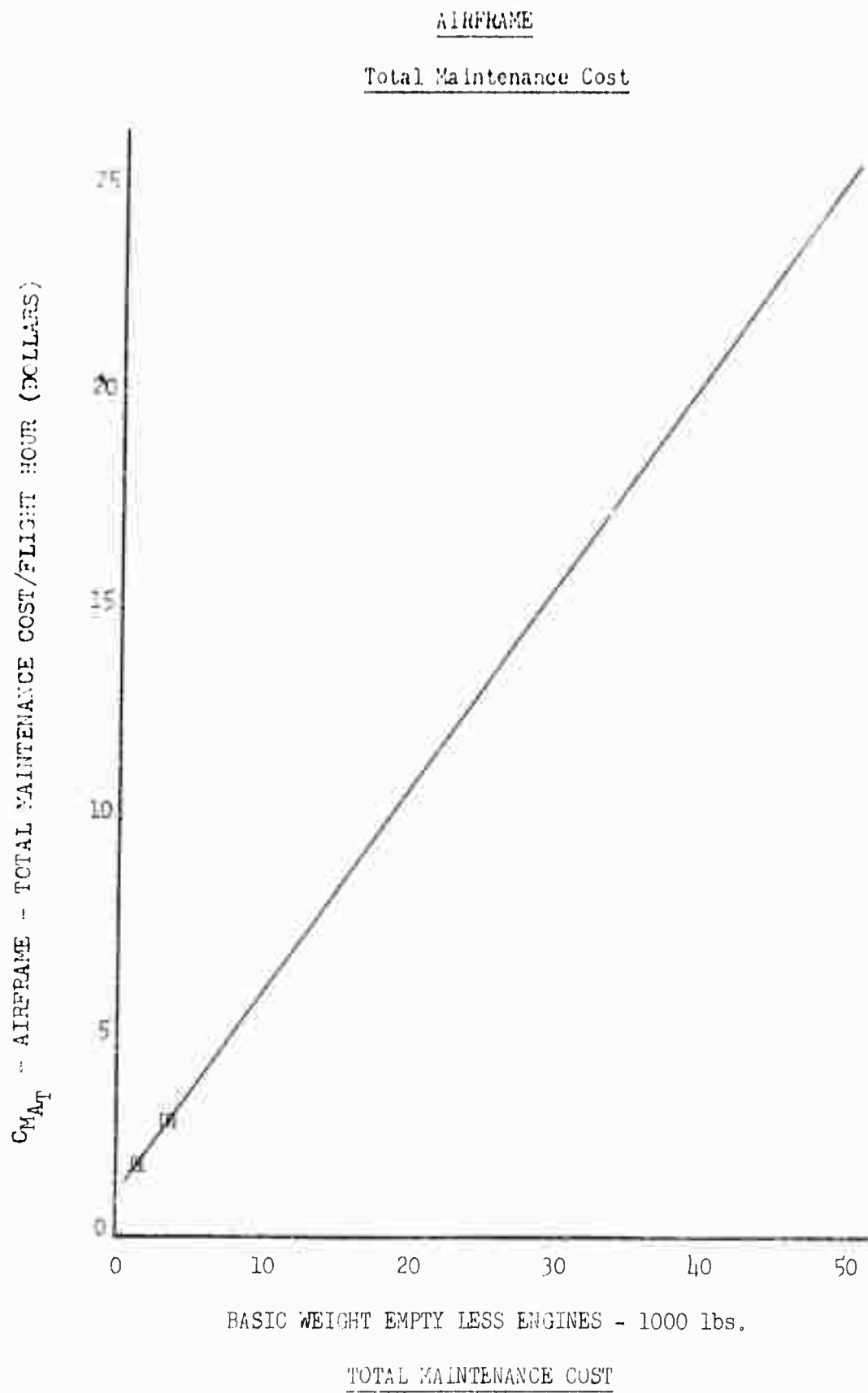
Total Maintenance Cost

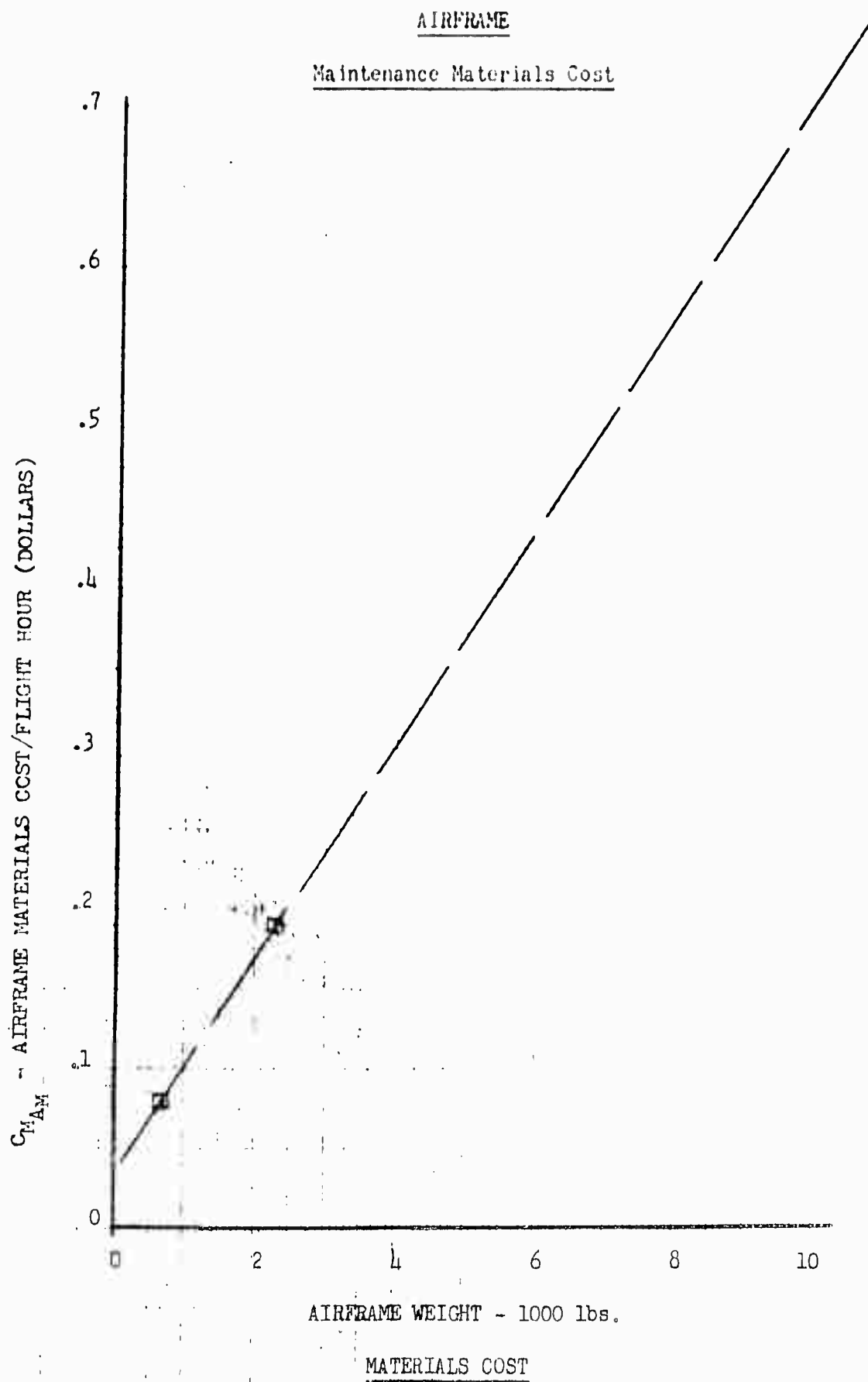
(labor and Materials)



AIRFRAME WEIGHT - 1000 lbs.

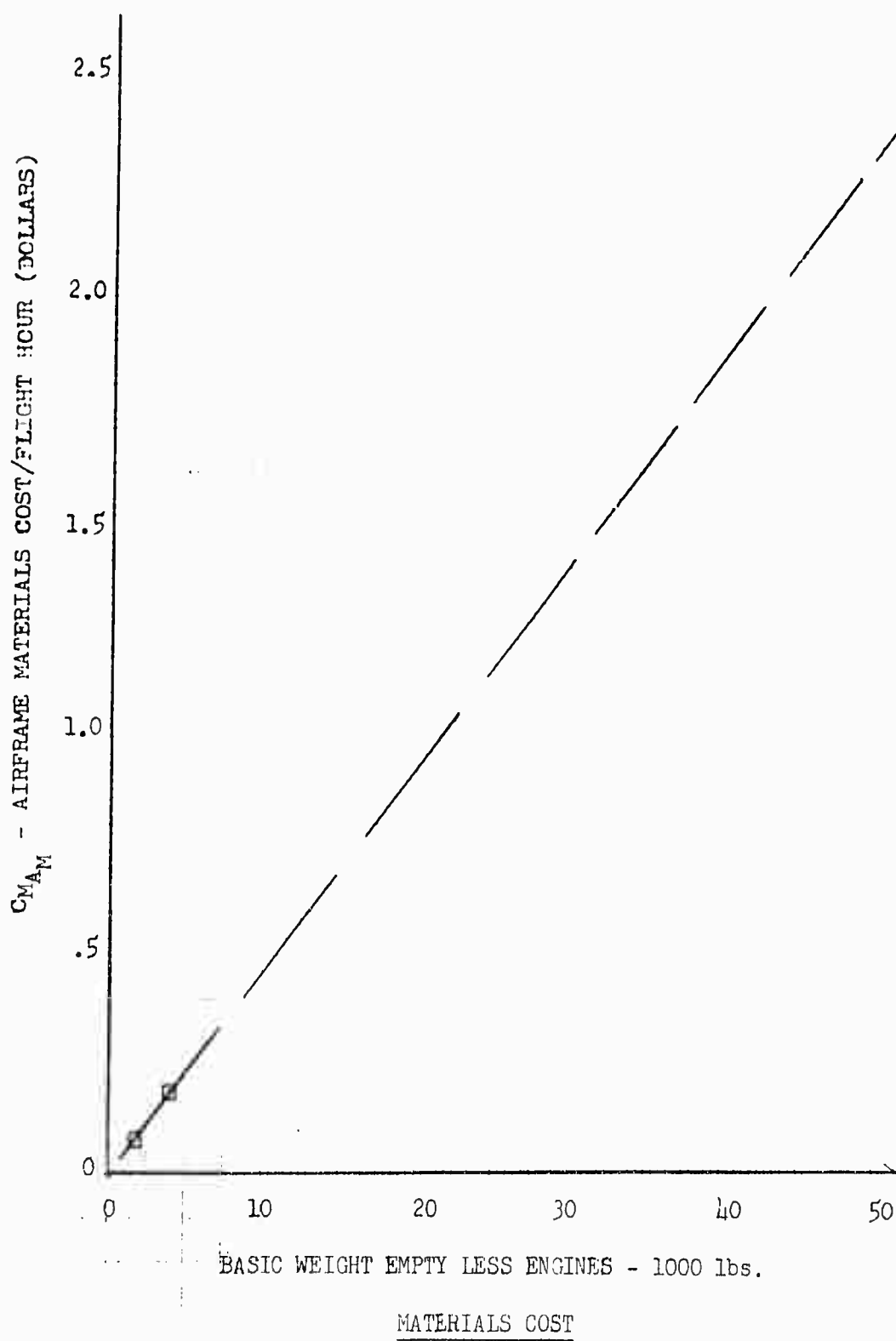
TOTAL MAINTENANCE COST





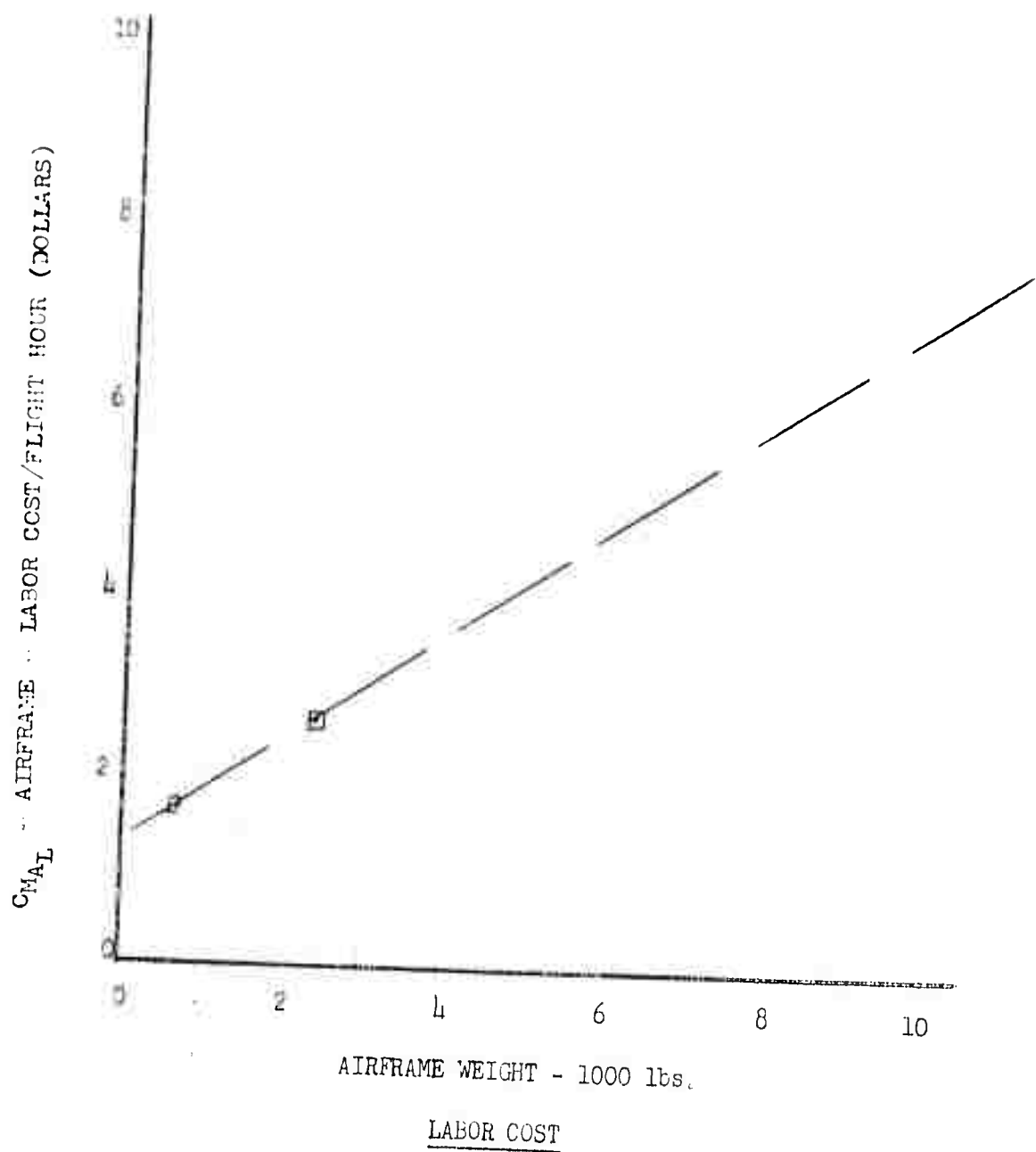
AIRFRAME

Maintenance Materials Cost



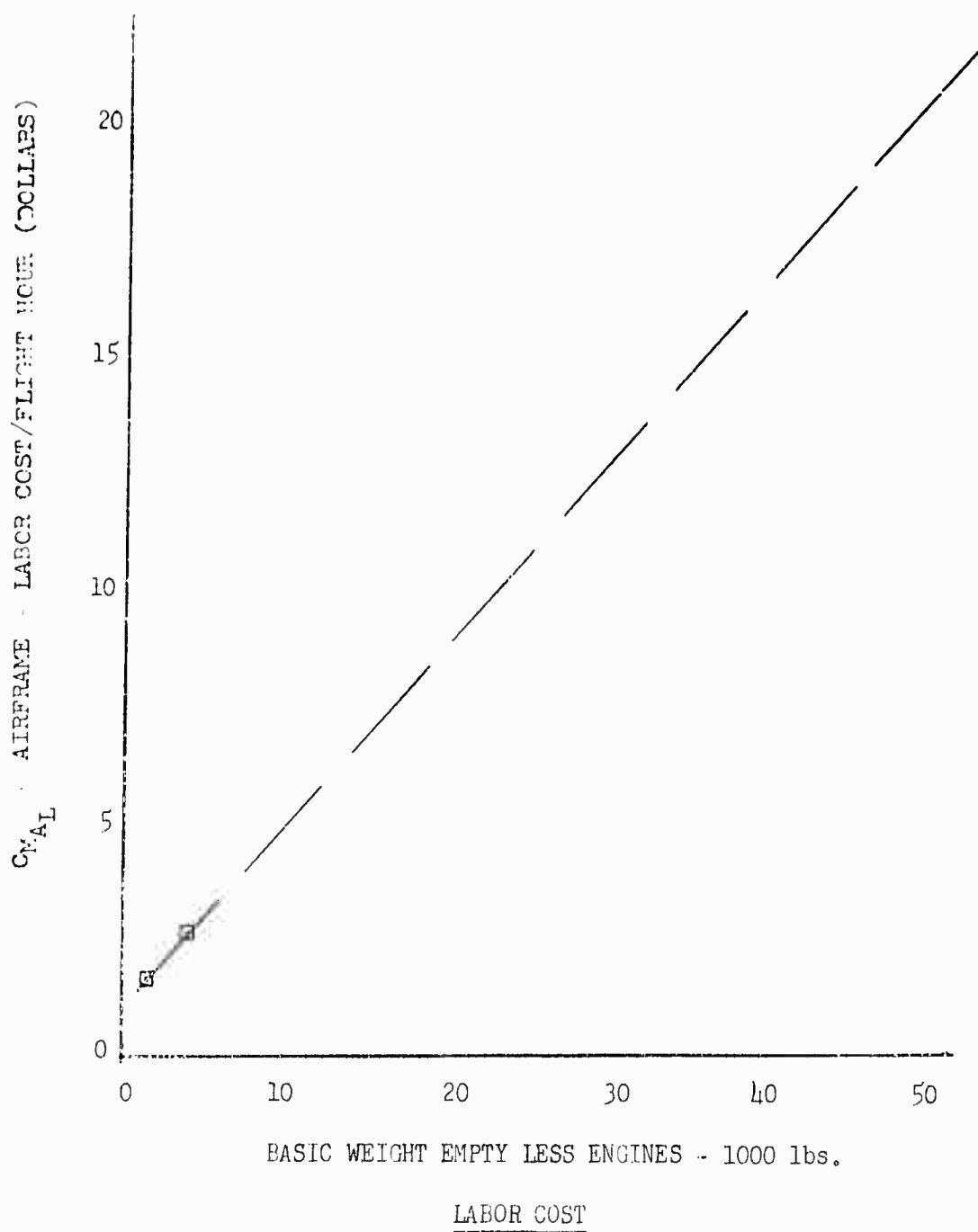
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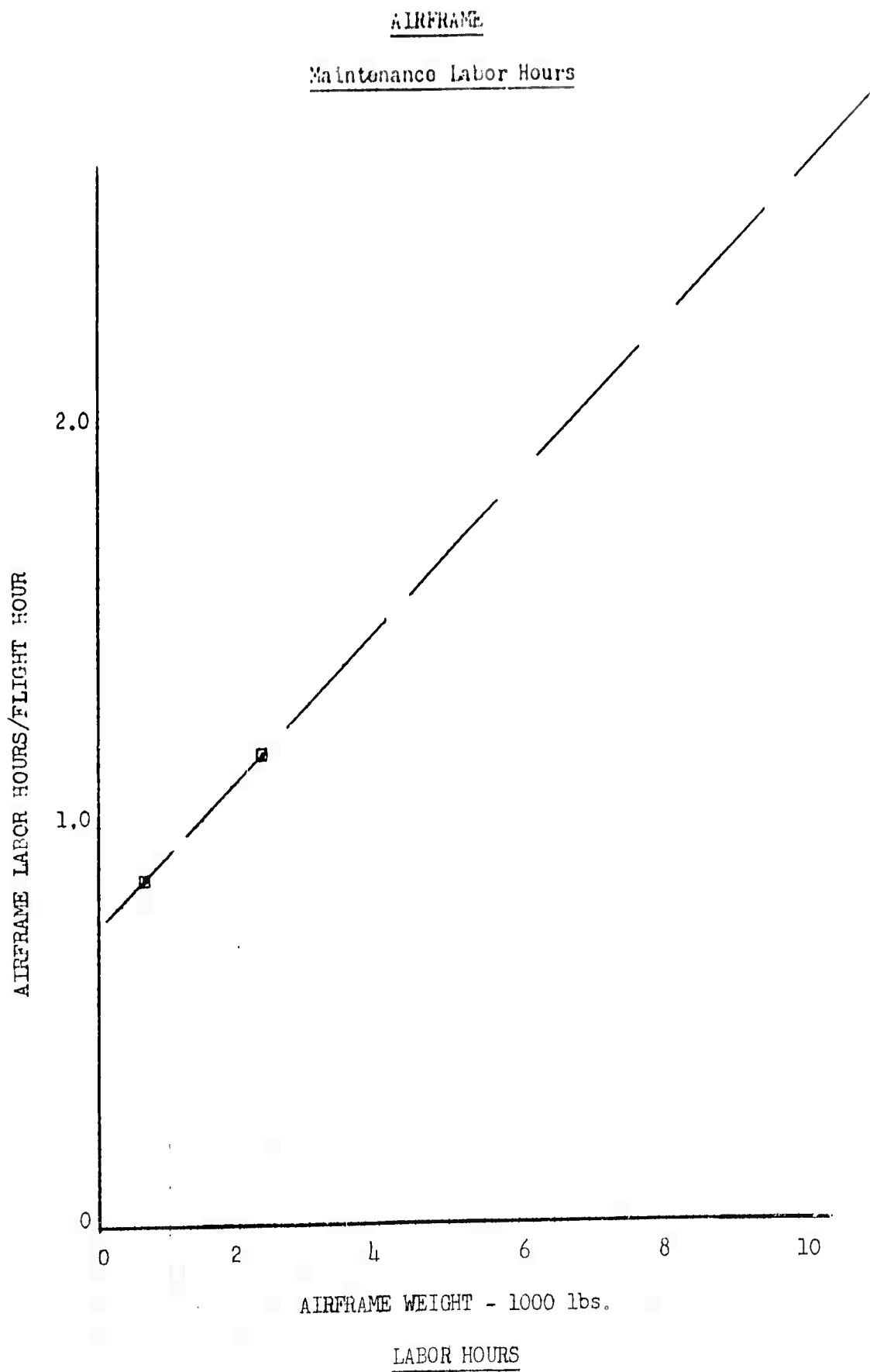
Maintenance Labor Cost

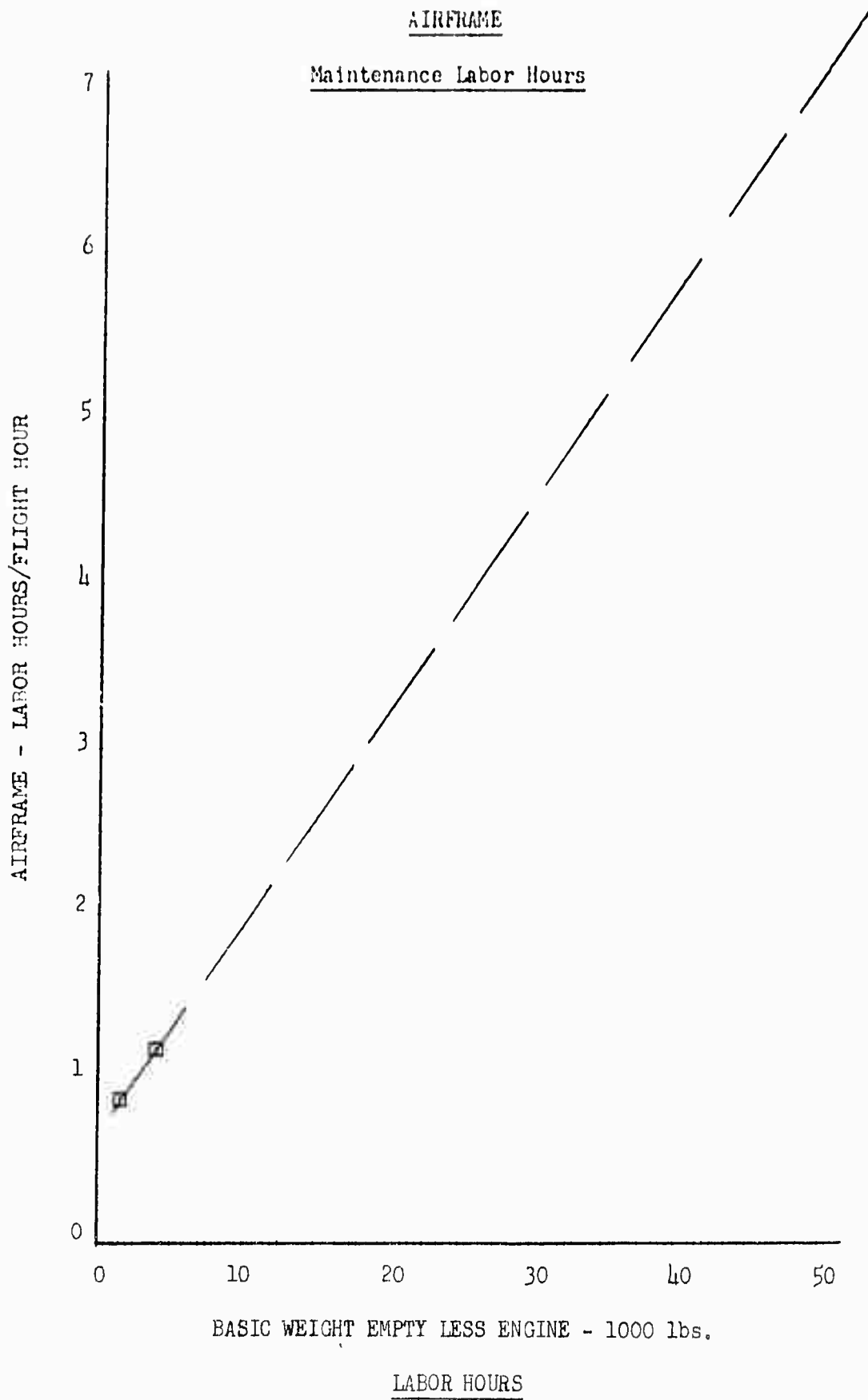


AIRFRAME

Maintenance Labor Cost





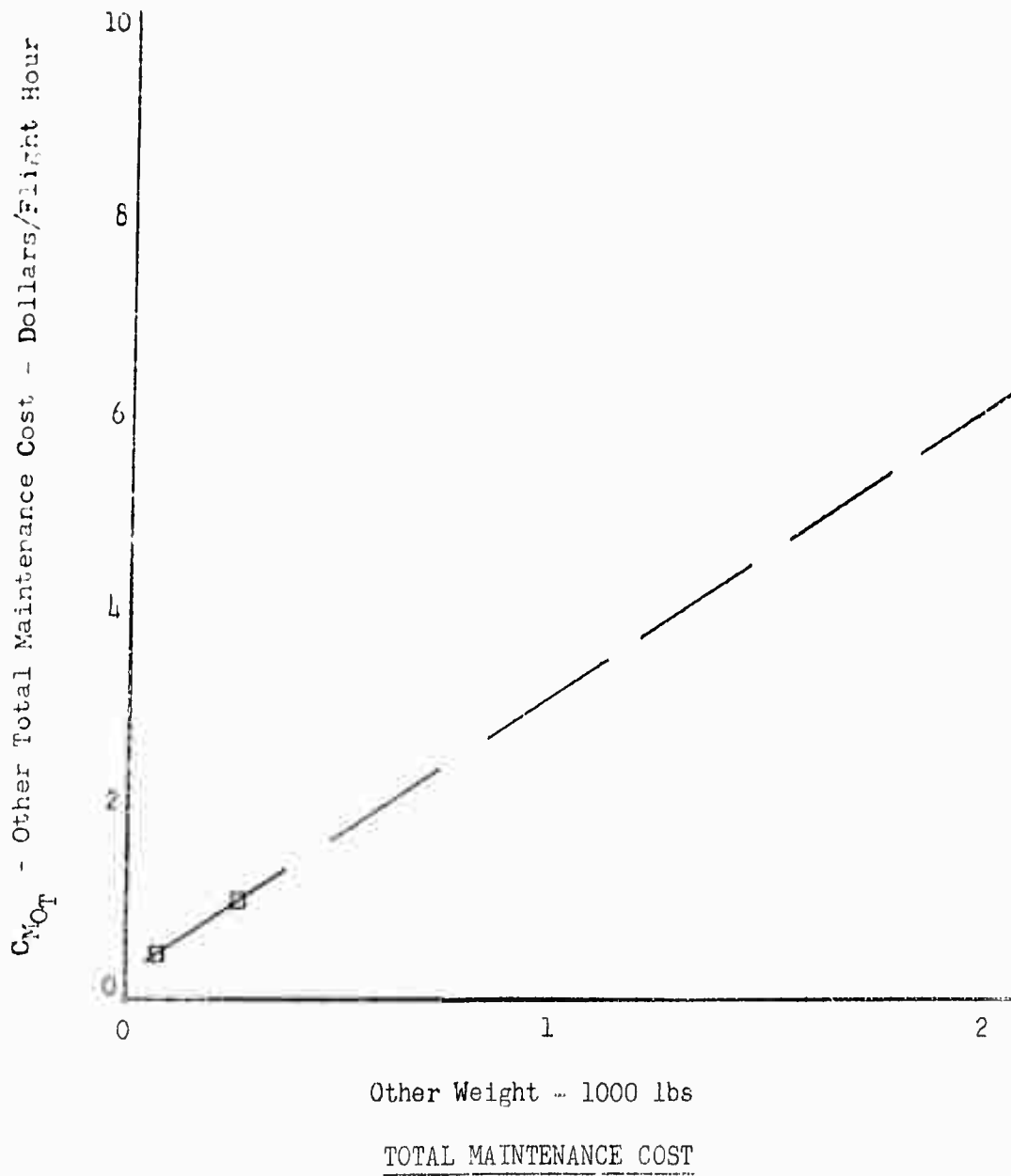


OTHER

(Radio & Instruments)

Total Maintenance Cost

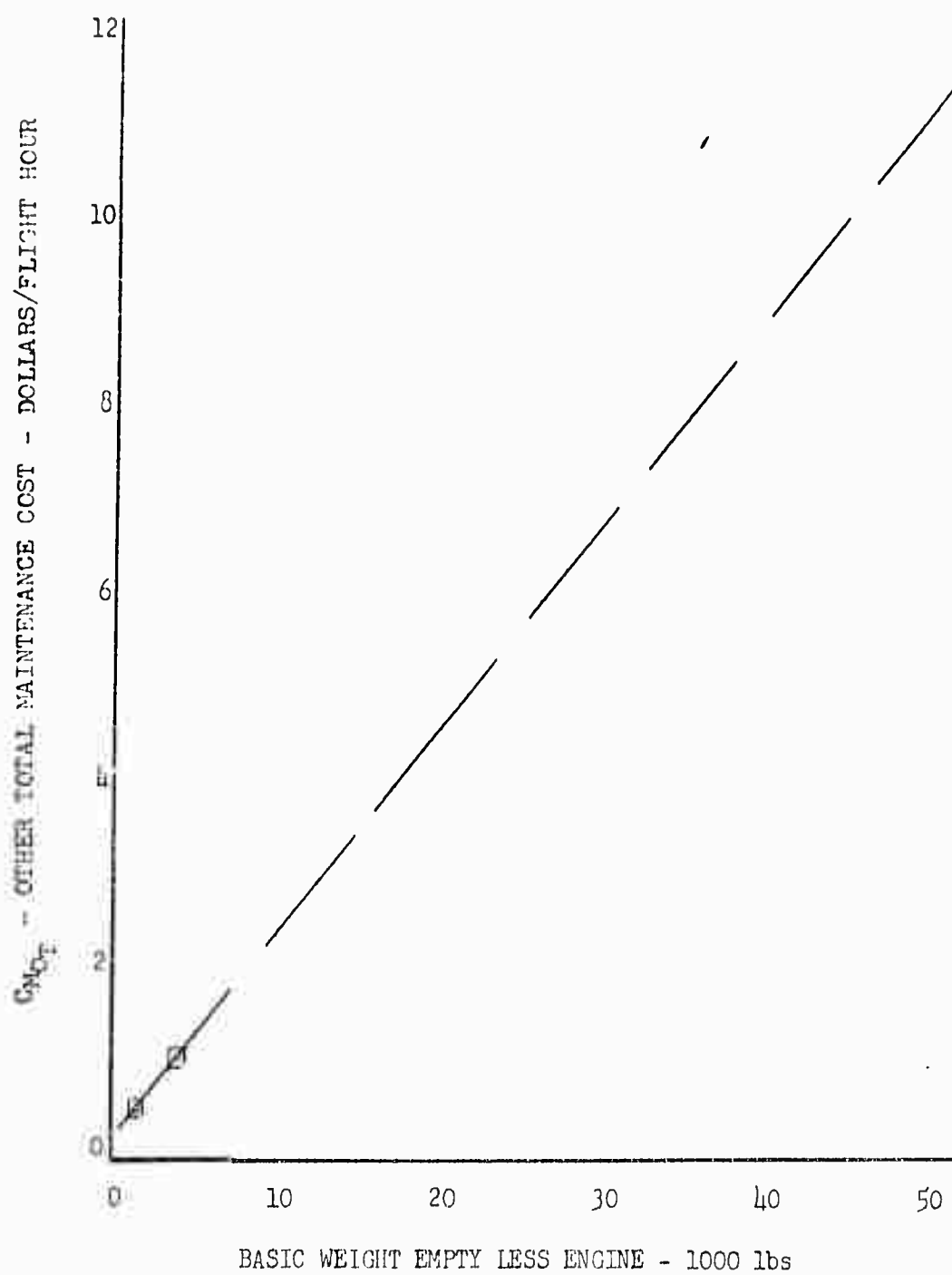
(Labor and Materials)



OTHER

(Radio & Instruments)

Total Maintenance Cost

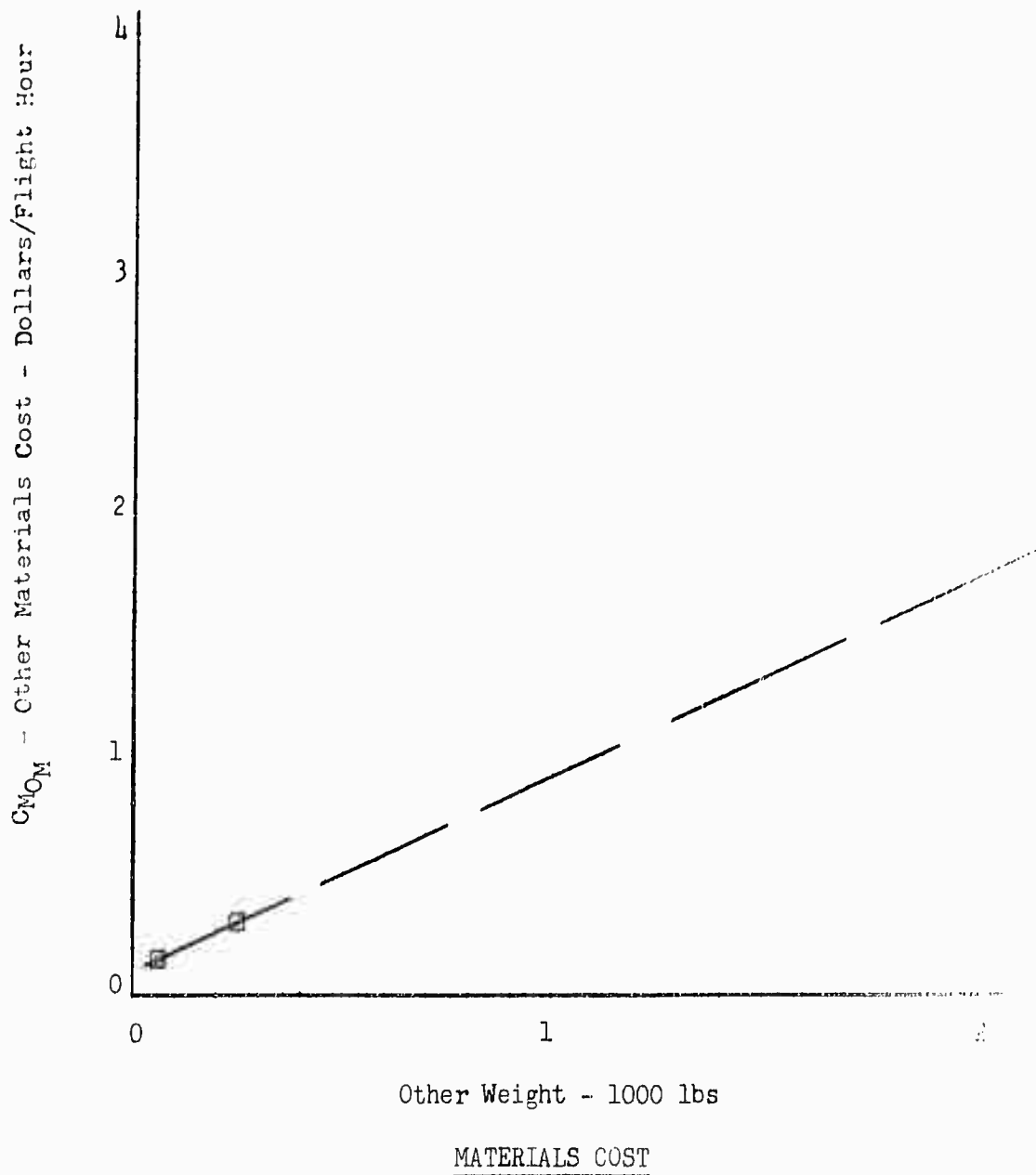


TOTAL MAINTENANCE COST

OTHER

(Radio & Instruments)

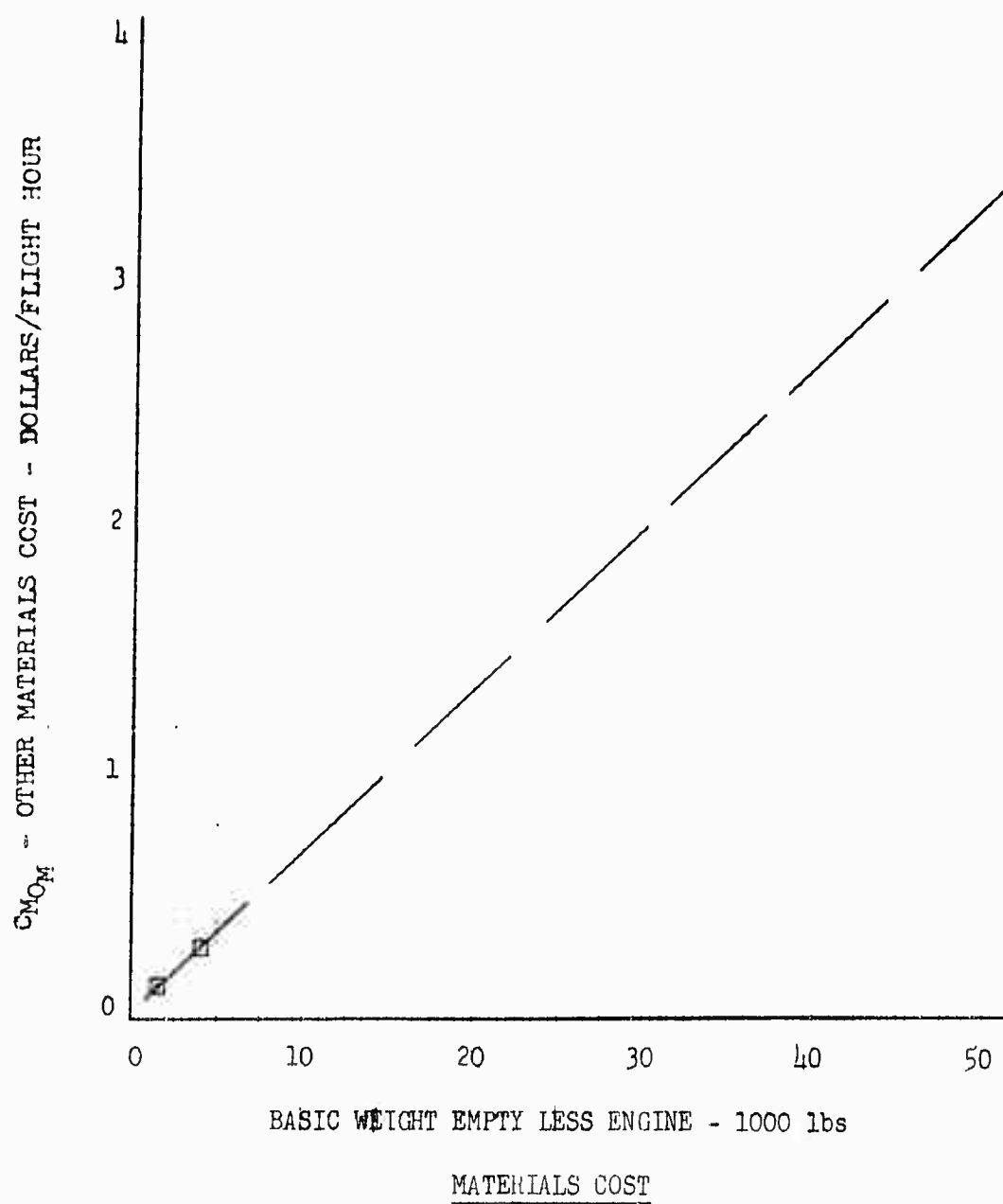
Maintenance Materials Cost



OTHER

(Radio & Instruments)

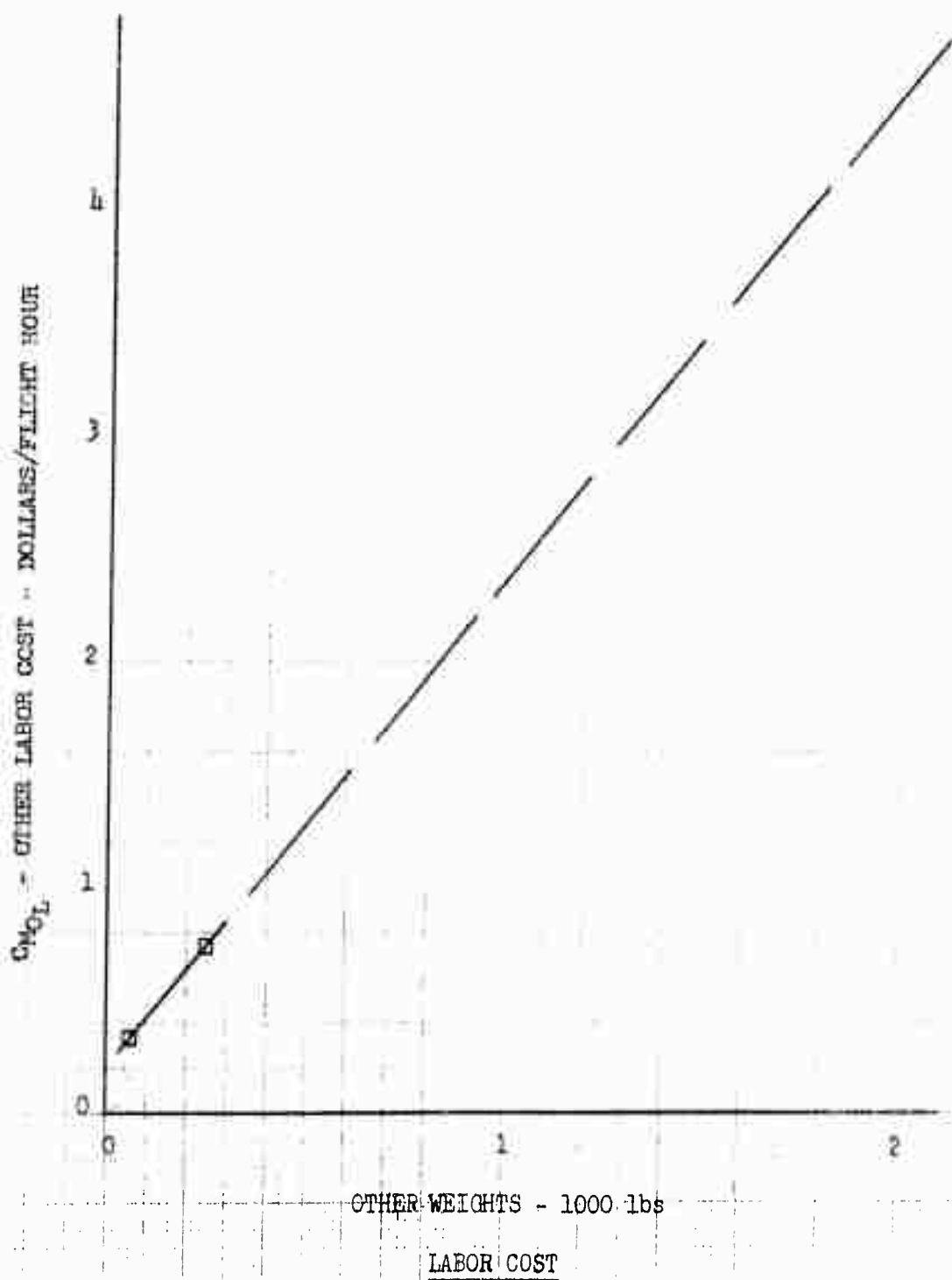
Maintenance Materials Cost



OTHER

(Radio & Instruments)

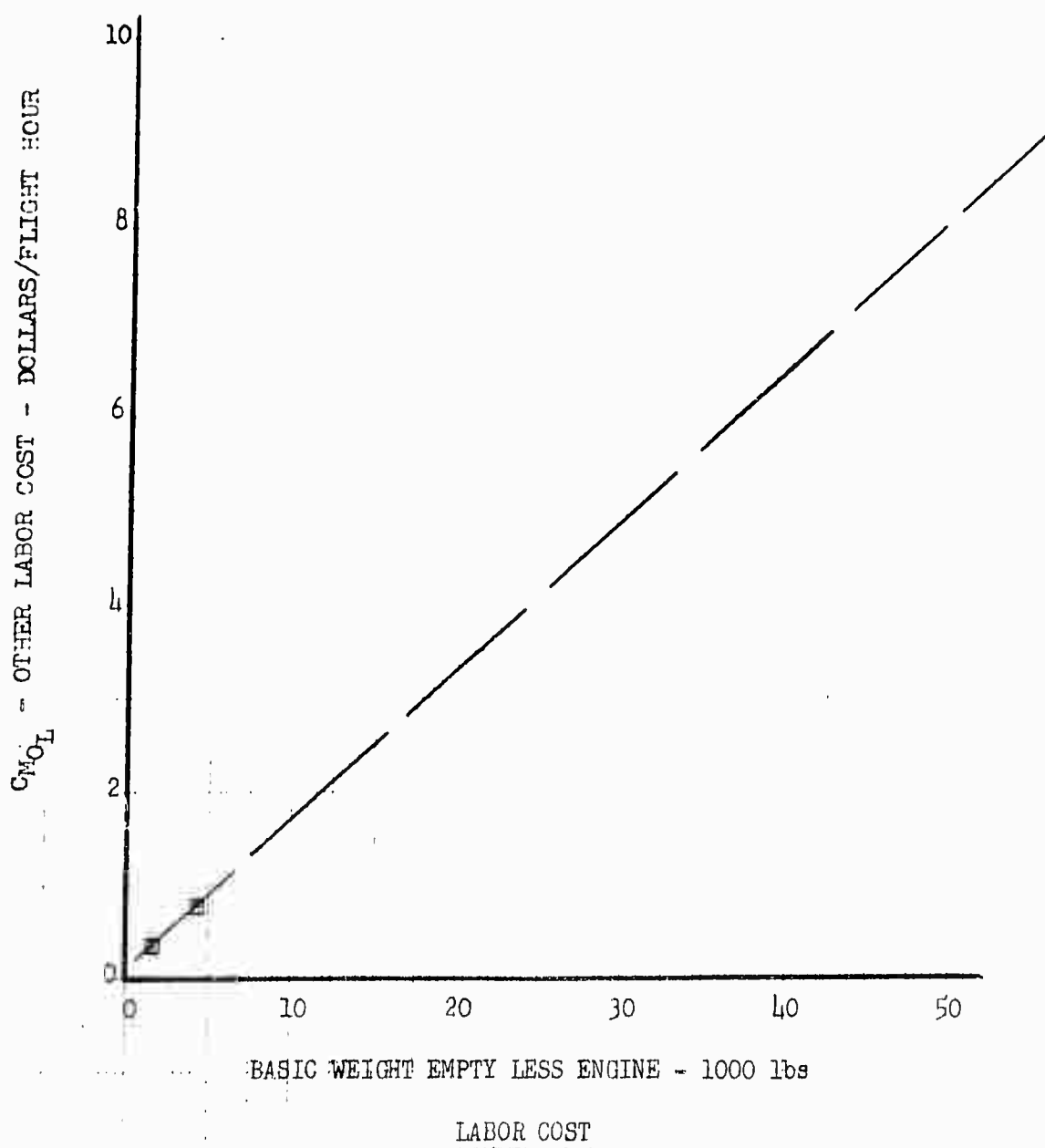
Maintenance Labor Cost



OTHER

(Radio & Instruments)

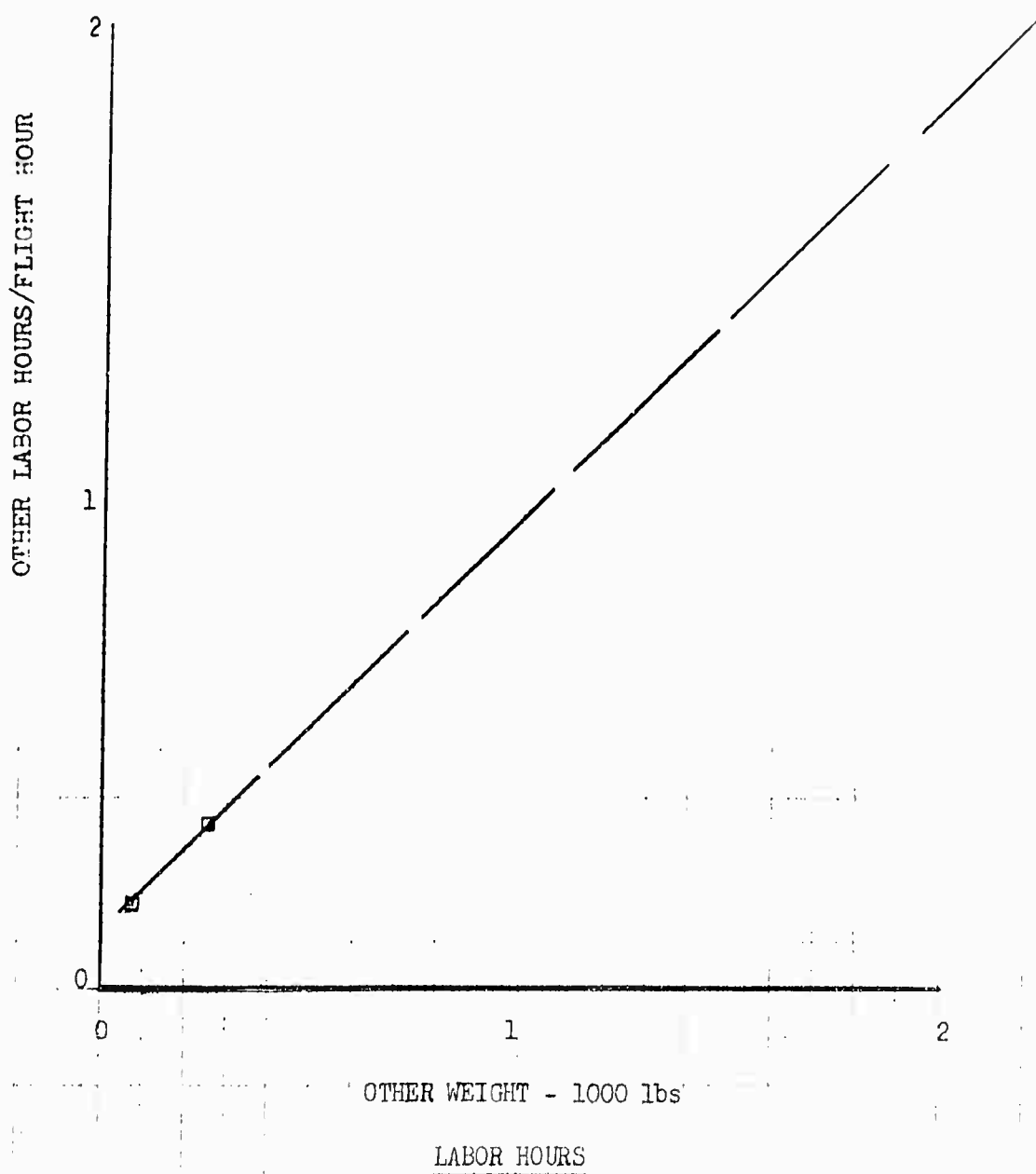
Maintenance Labor Cost



OTHER

(Radio & Instruments)

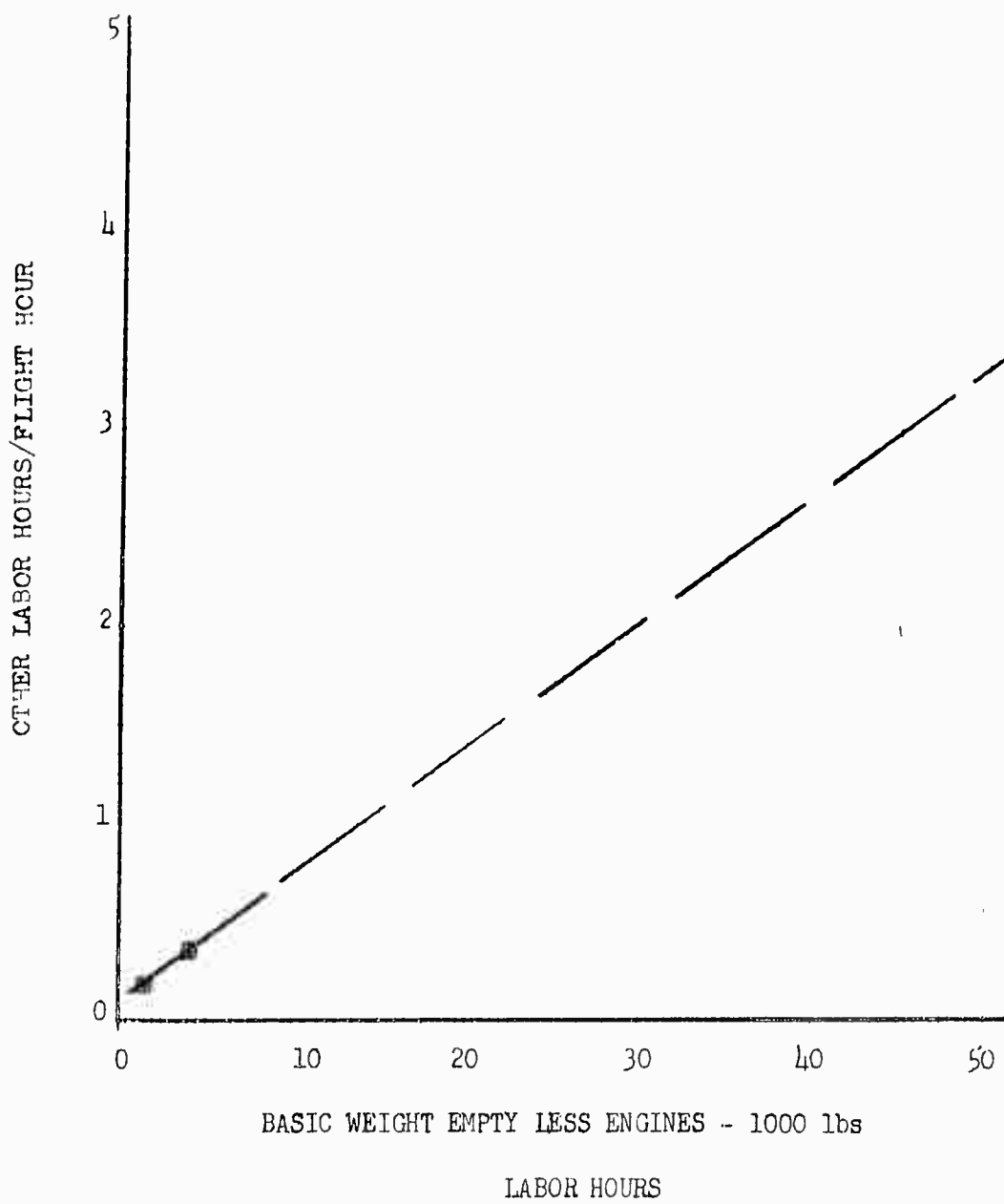
Maintenance Labor Hours



OTHER

(Radio & Instruments)

Maintenance Labor Hours



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IV. DEPRECIATION COSTS

A. INTRODUCTION

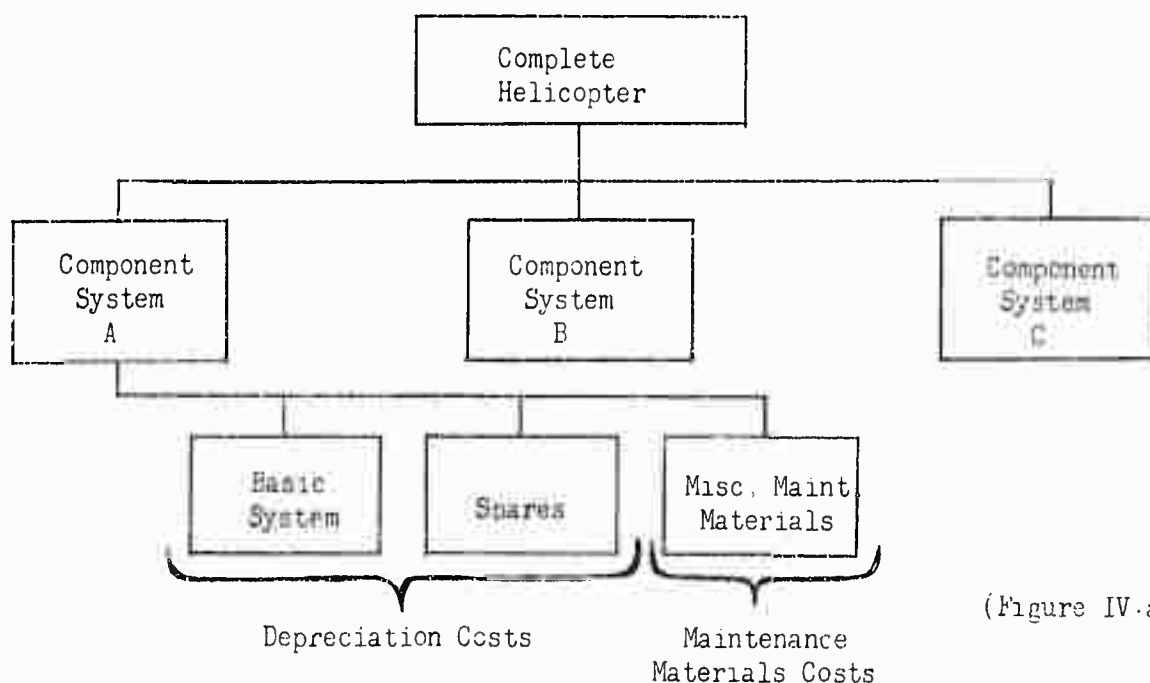
The parameters involved in developing expressions for depreciation costs are more easily obtained than those which are required in the maintenance cost development, but are, nevertheless, subject to close study and definition.

A number of different techniques used by the commercial operators in the U. S. have been studied and the variances found in method seem to be purely related to the particular operators organizational structure, financial situation and tax problems.

The results of the depreciation cost study have been based on as rational an approach as possible so that, in general, the technique would apply to any operation within the scope of a military helicopter logistic transport function.

Much confusion and debate has arisen over the question of whether or not maintenance material costs (miscellaneous replacement parts) should be considered as maintenance or depreciation cost items. The general consensus of opinion, however, of the fixed wing scheduled air carriers, is that replacement parts are definitely maintenance cost items, regardless of whether or not the replacement is necessary due to just random wear, or has a definite specified life limit. The following block diagram will explain the assumptions made in regard to this procedure for the subject study.

Schematic Block Diagram Showing Differentiation
Between Maintenance Material and Depreciation Costs



(Figure IV.a)

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The maintenance materials cost incurred by the replacement of parts due to random wear and specified limited life have already been included in the Maintenance Cost Analysis, Section III, of this report, for each of the component groups of the aircraft. In this section, therefore, consideration will be given only to the write-off of first cost plus spares cost. These are fixed costs which diminish with time while the maintenance materials cost is one which continues as long as the aircraft is operated.

B. FIRST COST WRITE-OFF

In order to facilitate the use of the data of this analysis for the cost evaluation of any proposed helicopter, regardless of type or configuration, the first costs have been developed on a unit (per pound) basis and have been separated into the same functional component groups as were used in the maintenance cost analysis; namely

	COMPONENT GROUP	SYMBOL (n)
(1)	Rotor System	RS
(2)	Transmission and Mechanical Drives	TD
(3)	Engine	E
(4)	Airframe	A
(5)	Other (radio and instruments)	O

Figure IV-b

The first cost depreciation for each of the (n) components may be calculated separately and then be summed up for any particular model under consideration.

The first cost write-off for any (n) component system may be expressed mathematically as follows:

$$C_{D1N} = \frac{C_{Un} W_n K_R}{D_p U} \quad (1)$$

where

C_{D1N}	=	Component system first cost write-off (Dollar/flt.hr.)
C_{Un}	=	Component system unit first cost (Dollar/lb.)
W_n	=	Component system weight (Lbs)
K_R	=	Residual constant (1 - % residual value at end of depreciation period)
D_p	=	Depreciation period (Years)
U	=	Yearly average aircraft utilization (Hrs/yr)

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C. SPARES COST WRITE OFF

The write-off cost of all spares must also be included to obtain a complete picture of the total depreciation cost for any (n) component system. This cost may be presented mathematically as follows:

$$C_{S_n} = C_{L_n} \sigma_n \quad (2)$$

where $\sigma_n = (W/S)_n$ = Number of component spares required per aircraft.

This, then, allows the formulation for the total depreciation cost for any component system to take the form:

$$C_{D_n} = (C_{D_{L_n}} + C_{S_n}) = \frac{C_{U_n} W_n (1 + \sigma_n) K_R}{D_{pU}} \quad (3)$$

where C_{D_n} = Total component system depreciation cost (Dollar/flt-hr.)

D. PRESENTATION OF DATA REQUIRED FOR THE DETERMINATION OF ALL COMPONENT DEPRECIATION COSTS

Each of the terms of Equation (3) must now be discussed and explained and all data necessary for the calculation of the parameters of Equation (3) will be presented.

1. Unit First Cost Determination

A study was carried out using the price data of several manufacturer's comprising both total aircraft prices as well as spares prices. The study was confined to the rotary wing manufacturer's for the establishment of present price levels, but fixed wing manufacturer's data was used in the determination of some price trends with aircraft component size or weight. In addition, by the appropriate use of cost estimating techniques and helicopter airframe manufacturer's data regarding production quantity effects on price, the unit component system prices were established for any arbitrarily chosen number of production units.

Assuming a production run of 200 airframes, the study results indicated the following unit component system first costs (C_{U_n}).

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Component System		C_{un} (Dollar/lb)
Airframe		\$ 34.50
Rotor System		28.50
Transmission and Mech. Drives		43.10
Engine	Reciprocating	20.00
	Tip Turbine	50.00
	Shaft Turbine	44.00
	Ramjet	22.00
Other (Radio and Instruments)		17.25

Note: 200
Production
Aircraft
Assumed.

Figure IV-c

The following chart will allow the conversion of the above tabular values of C_{un} for any assumed production run. The final corrected value for the unit cost item may then be written as

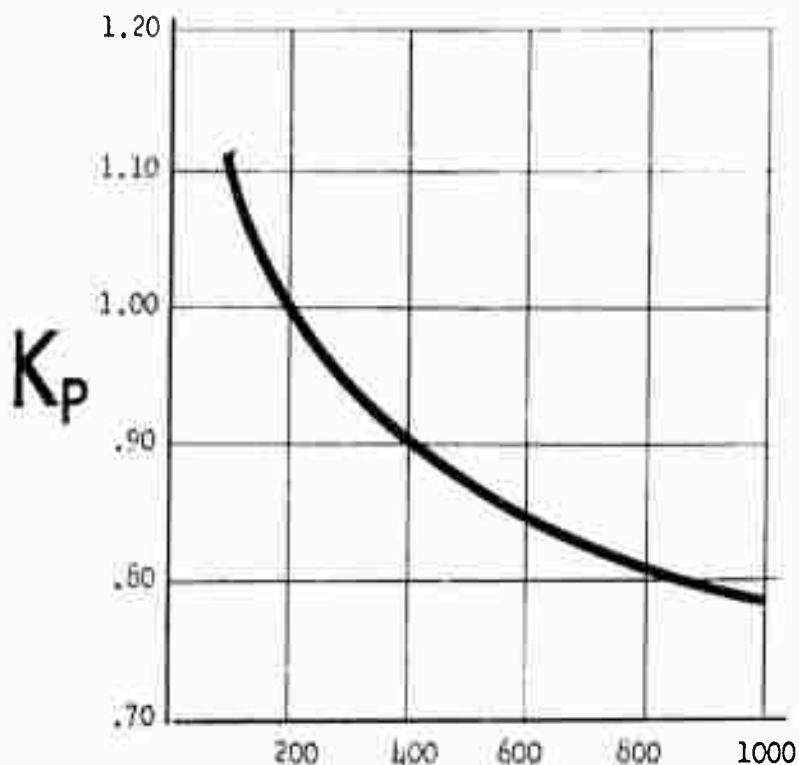
$$C_{unc} = K_P C_{un}$$

where K_P = Production quantity correction factor from the chart shown on the following page

and C_{unc} = Corrected unit first cost.

Note that at $N_S = 200$, $K_P = 1.00$.

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NS - No. Ships Procured

Figure IV-d PRODUCTION QUANTITY CORRECTION FACTOR

2. Spares Support Requirement

The number of spare parts required to support the operation of any helicopter operation is a function of the following three variables:

Aircraft utilization

Scheduled overhaul period

Overhaul turn-around time (time required to ship to an overhaul base, overhaul and return a component to stock)

For preliminary budgetary purposes, the U. S. Army sources advised the following relationship in determining the average spares support requirement per aircraft:

$$\sigma_n = (S/N)_n = \frac{t_n U/12}{OHP_n}$$

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where $\delta_n = (S/N)_n$ = Component system average number of spares per aircraft
 t_n = Component system average overhaul turn-around time (months)
 U = Average aircraft utilizations (Flt.hour/year)
 OHP_n = Average overhaul period of parts within a particular component system

In establishing preliminary provisioning estimates, U. S. Army practice has been to assume a 3-month turn-around time. This figure might seem rather high at first consideration, but becomes more easily understood upon close inspection of the complicated supply system used in supporting Army aircraft operations. Assuming this turn-around time to be a typical average for all component systems gives

$$\delta_n = \frac{U}{4(OHP_n)}$$

3. Determination of Overhaul Period (OHP_n)

From the techniques presented in Section III of this report, (Maintenance Costs), the average overhaul periods of engines and transmission and mechanical drives systems may be estimated. The estimated overhaul periods of the remaining components may only be based on past operational experience. This appears reasonable since the maintenance cost study did not indicate any greatly improved overhaul periods with improved "state of the art" in airframe or other component groups. The rotor system overhaul periods were found to be related primarily to the limited fatigue life of rotor system components, and a 5000-hour life was assumed for helicopters entering initial production in about 1960. It appears, however, that a shorter overhaul period than 5000 hours would be reasonable to allow for the scheduled inspection of the many mechanical components within the rotor system group.

Based on what has been mentioned above and on the advice of both commercial and Military operators, for the purposes of obtaining estimates on required spares support the following overhaul periods are suggested:

Engines - Determine from technique presented in Section III.

Transmission and Mechanical Drives - Determine from technique presented in Section III.

Rotor System - 1000 hours

Airframe - 8000 hours

Other - 1000 hours

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h. Selection of Depreciation Period and Residual Constant

Upon advice from U. S. Army sources, a depreciation period (D_p) of 5 years may be considered as typical of a military write-off time. Furthermore, this period may be assumed for all component systems.

In consideration of the fact that a good number of obsolete military aircraft are sold on the Government surplus market, a conservative residual value of 5 percent of initial cost will be assumed for all component systems. This yields a residual constant value of

$$K_R = .95$$

E. RECAPITULATION FOR PRESENTATION OF TOTAL DEPRECIATION COST

Referring to Equation (3) of Item C of this Section, the total depreciation cost may be written as

$$C_{D_{tot}} = (C_{D_{1n}} + C_{D_{Sn}}) = \sum_0^n \left[\frac{K_P C_{U_n} W_n (1 + \sigma_n) K_R}{D_P U} \right]$$

Since K_P , K_R and D_P have been assumed equal for all component system groups and since the further assumption that all component utilizations may be considered equal to the entire aircraft utilization, the above equation may be re-written as follows:

$$C_{D_{tot}} = \frac{K_P K_R}{D_P U} \sum_0^n \left[C_{U_n} W_n (1 + \sigma_n) \right]$$

Now substituting for K_R and D_P

$$C_{D_{tot}} = \frac{.19 K_P}{U} \sum_0^n \left[C_{U_n} W_n (1 + \sigma_n) \right]$$

Now substituting for σ_n gives

$$C_{D_{tot}} = \frac{.19 K_P}{U} \sum_0^n \left[C_{U_n} W_n \left(1 + \frac{U}{L(OHP_n)} \right) \right] \quad (4)$$

For use in preliminary design estimates, Equation (4) may be re-written as follows:

$$C_{D_{tot}} = \frac{.19 K_P}{U} \sum_0^n \left[C_{U_n} R_n W \left(1 + \frac{U}{L(OHP_n)} \right) \right] \quad (5)$$

where $R_n = \text{Component group weight to gross weight ratio } \left(\frac{W_n}{W} \right)$

$W = \text{Design gross weight}$

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The following values are retabulated below for use in Equation (4).

Component System Group	See Fig. IV-d $K_p = 1$	Estimated Average Overhaul Period	Comp. System Group Weight Lb.	Aircraft Average Utilization
n	C_{U_n} (Dollar/lb)	OHP_n (flt. hrs)	W_n	U
Airframe	34.50	2000	From weight breakdown of complete aircraft.	From estimates based on type and nature of the particular operation considered.
Rotor System	28.50	1000		
Transmissions and Mech. Drives	43.00	From techniques presented in Section III - Maintenance Costs		
Engines	Recip. 23.00			
	Turbine 34.50			
Other (Radio & Instruments)	17.25	1000		

Figure IV-e

F DISCUSSION OF TRANSPORT HELICOPTER UTILIZATION

Aircraft utilization is intimately related to the nature of the particular operation. The maintenance manpower and facilities available, the aircraft mission and the logistic problem are all items which have some effect on the average utilization used in any given operating cost analysis. These items are of considerable interest; however, as an inspection of Equation (4) will indicate, since minimum operating costs are realized as the utilization is increased.

The choice of a particular figure for use in any operating cost analysis is not covered in this discussion because of the factors mentioned above, but is left to the judgement of the reader when a particular study is contemplated.

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V. DEVELOPMENT COST

The development cost study, which utilized available helicopter development costs as a basis for establishing a level and fixed wing cost data for establishing the trend with weight, was made in an effort to obtain quantitative information which could be related to the aircraft's design parameters.

Shown in Figure V-1 is a plot of total development costs of airframes, including production engineering, tooling, manufacturing and ten percent profit, with the engine development costs for ramjets and tip turbojets also indicated.

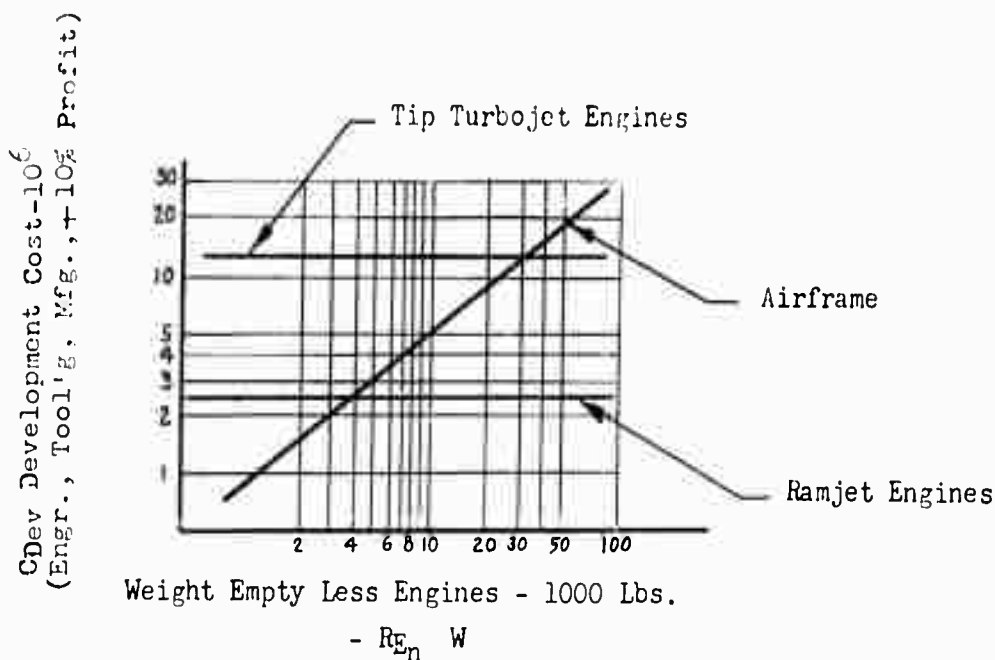


Figure V-1 DEVELOPMENT COSTS

Engine manufacturers' data indicates that the development costs for tip turbojet or ramjet engine power plants of the size applicable to configurations within the scope of this study are essentially constant with engine weight. The airframe development cost data is plotted versus the basic weight empty less engine weight.

The equation representing the airframe development costs can be written in the form:

$$C_{dev} = \frac{K_D K_{PI}}{P_W U N_S} \left(\phi - R_{EN} \right)^{\epsilon} W^{\epsilon}$$

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This equation puts the development cost on an average flight hour basis. Development cost data, presented in the curve, is indicative of 1954 prices.

P_W = write-off period (assumed five years)

U = aircraft average utilization (flight hours per year)

N_S = number of ships procured.

The same procedure as mentioned in the depreciation cost analysis discussion with regard to the production quantity adjustment factor was applied in selecting the proper value of N_S .

VI. TRAINING COSTS

Military training cost data indicated helicopter pilot training cost to be \$36,000, and helicopter mechanic training costs of \$3900. These costs include field and organizational maintenance training, student pay, fuels, instructors, direct cost of supervisors, training aids, and a proportionate amount of the indirect costs chargeable to the training program. The flight crew was assumed to consist of a pilot, co-pilot and flight engineer for all helicopters considered. Flight engineer training costs were assumed to be twice that of mechanic training costs, in the absence of specific information for this category. This gave a total flight crew training cost of approximately \$80,000.00.

For the calculation of mechanic training costs, the number of mechanics per aircraft was based on the curve of Figure VI-1 which was derived from commercial helicopter operators' data, and includes the total depot overhaul maintenance support as well as line and second echelon maintenance on all components.

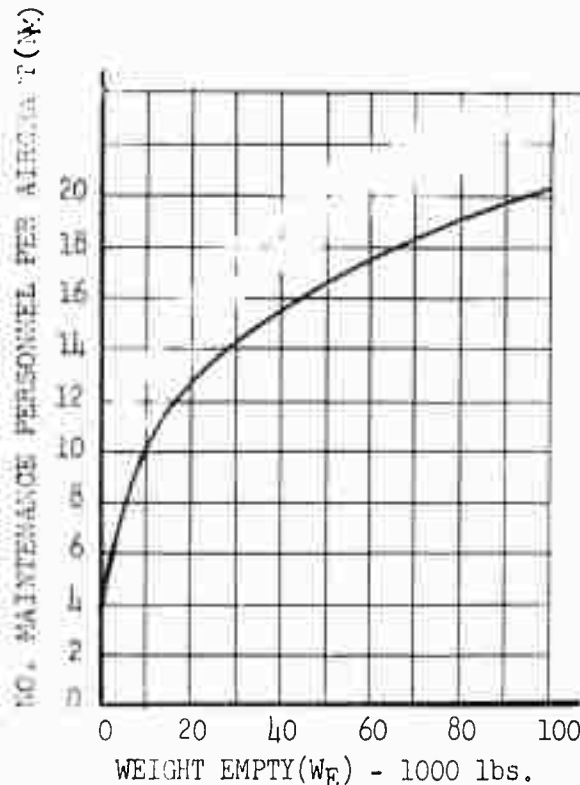


Figure VI-1: EFFECT OF HELICOPTER EMPTY WEIGHT ON TOTAL NUMBER OF MAINTENANCE PERSONNEL REQUIRED PER HELICOPTER

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The equation used for predicting total training cost on a flight hour basis was:

$$C_T = \frac{K_{PI}}{U P_S} \left[C_{T_{FC}} + K_{CM} \times C_{T_M} \times N_M \right]$$

Where

- $C_{T_{FC}}$ = Flight crew training cost in dollars (\$60,000.00)
- K_{CM} = Military cost correction factor (2.5) (See Section III)
- C_{T_M} = Mechanic training cost (\$3900.00)
- N_M = Number of mechanics per aircraft
- P_S = Average service period of the flight crew and maintenance personnel (years)
- U = Aircraft utilization (hours/years)
- K_{PI} = Price index correction factor

Although the factor K_{CM} has been shown previously as a cost scale up factor, military maintenance and manpower statistics have indicated the justification of its application to labor hours and manpower as well. The factor K_{CM} is therefore included to allow for the additional mechanics in training together with rear base and Zone of the Interior maintenance supply and support personnel.

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